AN INVESTIGATION OF STOCHASTIC FRONTIER PRODUCTION FUNCTIONS INVOLVING FARMER CHARACTERISTICS USING ICRISAT DATA FROM THREE INDIAN VILLAGES

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ABSTRACT

This study applies the Battese and Coelli (1992) stochastic frontier production function for panel data, in which the technical inefficiency effects are an exponential function of time, in the analysis of farm-level data from three Indian villages. The parameters of the stochastic frontier are assumed to be linear functions of time and the farmer characteristics, age and years of formal schooling. Given that the three different villages in the study were chosen by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as representative of different agricultural systems in the semi-arid tropics of India, it is not surprising that different models for technical inefficiencies are preferred in the villages involved. In one village, the traditional average-response model is an adequate representation for the data, that is, the technical inefficiency effects are not significant. Although the inefficiency effects are significant in the other two villages, in one of these villages the technical inefficiencies are found to be time invariant.

The parameters of the stochastic frontiers are found to be time-invariant in one of the villages. The age of the primary decision maker in the farming operation did not have a significant effect on the parameters of the production frontiers for any of the three villages.

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1 Introduction

Frontier production functions are useful to provide information about the relationship between the amount of output and the inputs of production, given the level of technology involved. In recent years, the modelling of frontier production functions has been a subject of considerable interest in economic and econometric research. Attempts have been made to define and apply specific models for individual firms. Battese (1992) surveys a review of the concepts and models suggested, and presents empirical applications appearing in agricultural economic journals. The introduction of the stochastic frontier production function model, independently proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), gave rise to the development and application of similar models in the analysis of data from industrial and agricultural firms. Battese and Tessema (1993) recently applied and estimated a stochastic frontier production function model with time-varying parameters and technical inefficiencies using panel data from Indian villages. This study extends the analysis in Battese and Tessema (1993) by considering the possible effects of characteristics of farmers, in addition to the effect of time, on the coefficients of the frontier production functions for the same data set for three Indian villages.

2 ICRISAT's Village Level Studies

The data used in this study are obtained from the Village Level Studies (VLS) conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) during the years 1975 to 1985. Data from the three villages of Aurepalle, Shirapur and Kanzara, which have different agro-climatic conditions, are considered in this paper.

Soil heterogeneity conditions are remarkably great in Aurepalle compared with the other two villages. Kanzara exhibits the least amount of soil heterogeneity. Aurepalle has medium and shallow red soils with low water-retention capacity. Shirapur has medium and deep black soils with high moisture-retention capacity. Kanzara has mainly medium-deep black soils and shallow vertisols with medium moisture-retention capacity.

Mean annual rainfall ranges from around 400 mm to 12000 mm and is generally irregular in the study area. During 1975 to 1985, the average annual rainfall was 611 mm, 629 mm and 850 mm for Aurepalle, Shirapur and Kanzara, respectively. Rainfall is less uncertain and uneven in Kanzara than in Aurepalle and Shirapur. Walker and Ryan (1990) report that during four years in the study period Aurepalle and Shirapur had very little rainfall.

There are two main seasons prevailing in the study area, namely, the rainy (kharif) season which occurs during the months of June to October, and the post-rainy (rabi) season during the rest of the year. Rainfall during the rabi season occurs more frequently in Shirapur. There is relatively more reliable rainfall in Kanzara during the kharif season. The percentages of the total cultivated land that is irrigated in Aurepalle, Shirapur and Kanzara are 22, 10 and 8 per cent, respectively. Furthermore, the percentages of farmers without any irrigation in Aurepalle, Shirapur and Kanzara are 59, 60 and 72 per cent, respectively. This indicates that most farmers in the three villages mostly rely on rainfall for agricultural production.

Intercropping is more prevalent in Kanzara than in the other two villages. Likewise, the use of improved technology, such as high-yielding varieties, fertilizers and pesticides, is also higher in Kanzara.

The labour market, which includes cultivators and agricultural labourers, involves about two-thirds of the available workers in the study area. However, the use of hired and family labour, varies for each village from year to year. This is dependent on rainfall, soil type, type of crop, irrigation, etc. In Aurepalle and Kanzara, hired labour comprises around 60 to 80 per cent of the total labour used in crop production. The labour force comprises men, women and children. Men usually contribute more for family labour while women dominate the hired-labour market.

Activities, such as plowing, harrowing and interculturing, are carried out using animal draft power, generally by the use of bullocks. Occasional hiring of bullock labour occurs for households which do not own bullocks, usually among farmers having small areas to cultivate. This is most common in Shirapur where bullock labour-to-land ratios are significantly lower (Walker and Ryan, 1990). Single bullock owners often pool together their bullocks and work together on an exchange basis.

The numbers of farmers involved in the sample data in the three villages are 34, 35 and 33 from Aurepalle, Shirapur and Kanzara, respectively. The total number of yearly observations for the farmers involved are 273,268 and 289 from Aurepalle, Shirapur and Kanzara, respectively. A statistical summary of some important variables concerned in the study is presented in Table 1. From this table, we see that Aurepalle farmers have a higher mean age of 54 years as compared with 48 years in Shirapur and 44 years in Kanzara. Farmers in the study area have only a few years of formal education, with Aurepalle having the lowest average of only two years of schooling and Shirapur the highest average, which is only four years. Moreover, there are 61 per cent of farmers in Aurepalle without any formal education, whereas in Shirapur and Kanzara the percentages are 38 and 40 per cent, respectively.

Table 1: Statistical Summary of Variables for Farmers in Aurepalle, Shirapur and Kanzara

Variable	Sample Mean	Sample Standard Deviation	Minimum Value	Maximum Value	Percentage of Zero Observations
Value of Output (Rs, in 1975-76 values)					
- Aurepalle	3679.6	4559.2	10.15	18094	-
- Shirapur	3270.7	3482.7	22.00	26423	-
- Kanzara	5231.3	7226.5	121.58	39168	-
Age of Farmer					
- Aurepalle	53.9	12.6	26	90	-
- Shirapur	48.2	10.2	24	72	-
- Kanzara	43.7	9.6	23	67	-
Years of Formal Education of Farmer					
- Aurepalle	2.0	2.9	0	10	61.2
- Shirapur	2.9	3.4	0	16	38.4
- Kanzara	4.0	4.1	0	12	40.1
Land (hectares) = Irrigated + Unirrigated Land					
- Aurepalle	4.29	3.87	0.2	20.97	-
- Shirapur	6.68	5.49	0.6	24.19	-
- Kanzara	6.02	7.40	0.4	36.34	-
Irrigated Land (hectares)					
- Aurepalle	0.95	1.41	0	7.09	59.0
- Shirapur	0.64	1.07	0	4.96	60.1
- Kanzara	0.51	1.22	0	9.79	71.6
Labour (hours) = Hired + Family Labour					
- Aurepalle	2206.2	2744.1	26	12916	-
- Shirapur	1674.8	1576.9	40	11146	-
- Kanzara	2578.5	3145.7	58	15814	-
Hired Labour (hours)					
- Aurepalle	1468.3	2349.6	0	11662	6.2
- Shirapur	719.1	768.4	24	4823	-
- Kanzara	1841.2	2852.3	6	14130	-
Bullock Labour (hours of bullock pairs)					
- Aurepalle	528.2	604.6	8	4316	-
- Shirapur	342.3	282.2	14	1240	-
- Kanzara	570.6	765.1	12	3913	-
Cost of Other Inputs (Rs)					
- Aurepalle	651.02	981.06	0	6205	21.3
- Shirapur	464.49	1038	0	6746	32.1
- Kanzara	628.96	978.49	0	5344	13.8

Farmers in Kanzara are producing more when considered in terms of value of output as indicated by an average amount of Rs 5,231, whereas Aurepalle and Shirapur farmers have an average value of output of only Rs 3,680 and Rs 3,271, respectively. Shirapur farmers cultivate a larger amount of land with an average total land, i.e., irrigated and unirrigated land, of 6.7 hectares as compared with an average of 4.3 hectares in Aurepalle and 6.0 hectares in Kanzara. However, farmers in Aurepalle have a larger area of irrigated land cultivated with a mean of 1.0 hectares. Labour hours, i.e., hired and family labour, are greater in Aurepalle and Kanzara with an average of 2206 and 2579 hours per farmer, respectively. Shirapur farmers use an average of 1675 hours of labour. Likewise, Aurepalle and Kanzara farmers hire more labour for their farming operations, with an average of 1468 and 1841 hours, respectively. Shirapur farmers use an average of only 719 hours of hired labour on their farms. Moreover, Aurepalle and Shirapur farmers use more bullock labour hours and expend more on other inputs in their farming operations.

3 The Stochastic Frontier Model

The stochastic frontier production function considered for farmers in a particular village is defined by

$$\begin{aligned} ln Y_{it} = {} & \beta_{0t} + \beta_{1t} ln(\text{Land}_{it}) + \beta_{2t} ln(\text{Labour}_{it}) + \beta_{3t} ln(\text{Bullock}_{it}) \\ & + \beta_{4t} ln(\text{Cost}^*_{it}) + \beta_{5t}\left(\frac{IL_{it}}{\text{Land}_{it}}\right) + \beta_{6t}\left(\frac{HL_{it}}{\text{Labour}_{it}}\right) + V_{it} - U_{it} \end{aligned} \quad (1)$$

where

$$\beta_{jt} = \beta_j + \alpha_j(\text{Age}_{it}) + \delta_j(\text{Educ}_{it}) + \varepsilon_j(\text{Year}_{it}), \; j = 0,1,\ldots,6; \text{ and} \quad (2)$$

$$U_{it} = \{\exp[-\eta(t - T)]\} U_i, \quad t = 1,2,\ldots,T_i; \; i = 1,2,\ldots,N; \tag{3}$$

where the subscripts i and t represent the i^{th} farmer and the t^{th} year, respectively;

Y_{it} is the total value of output (expressed in thousands of Rupees) for the i^{th} farmer in the t^{th} year of observation (expressed in 1975-76 value terms)[2];

$Land_{it}$ is the total area of land in hectares which includes irrigated and unirrigated crop production area operated by the i^{th} farmer in the t^{th} year of observation;

$Labour_{it}$ is the total quantity of family and hired labour (in thousands of man hours[3]) for the i^{th} farmer in the t^{th} year of observation;

$Bullock_{it}$ is the total amount of bullock labour (expressed in thousands of hours) which includes hours of owned and hired bullock labour for the i^{th} farmer in the t^{th} year of observation;

$Cost^*_{it}$ is the total cost of other inputs (expressed in thousands of Rupees), which includes costs of inorganic fertilizer used, organic matter applied, pesticides used, and machinery costs for the i^{th} farmer in the t^{th} year of observation, given that the total costs are positive, but $Cost^*_{it}$ has

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[2] The values of output and input costs are deflated using price indices constructed from data on prices and quantities of commodities grown in the villages involved.

[3] ICRISAT uses the conversion that 1 hour of female labour is equivalent to 0.75 man hours, and 1 hour of child labour is equivalent to 0.50 man hours.

value, one, if total costs of other inputs are zero[4];

IL_{it} is the irrigated land in hectares that is operated by the i^{th} farmer in the t^{th} year of observation;

HL_{it} is the quantity of hired labour (expressed in thousands of man hours) employed by the i^{th} farmer in the t^{th} year of observation;

Age_{it} is the age (in decades) of the i^{th} farmer in the t^{th} year of observation;

$Educ_{it}$ is the number of years of formal education of the i^{th} farmer in the t^{th} year of observation;

$Year_{it}$ indicates the year of observation involved for the i^{th} farmer in the t^{th} year of observation (expressed in terms of 1,2,...,10);

the V_{it}'s are assumed to be independent and identically distributed $N(0,\sigma_V^2)$ random variables;

the U_i's are assumed to be independent and identically distributed non-negative truncations of the $N(\mu,\sigma^2)$ distribution;

the random variables, V_{it} and U_i, are assumed to be mutually independent and independent of the input variables in the model;

η is an unknown scalar parameter;

T_i represents the number of yearly observations available for the i^{th} sample farmer in the village involved;

N represents the number of sample farmers in the village involved, where N = 34, 35 and 33 for Aurepalle, Shirapur and Kanzara, respectively; and

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4 The fourth explanatory variable in the model is alternatively expressed in terms of the dummy variable, D_{it}, which has value, one, if $Cost_{it}$ is positive and has value, zero, otherwise, as follows:

$$Cost^*_{it} = Max(Cost_{it}, 1 - D_{it}).$$

ln is logarithm to the base, e.

The variables in the production frontier are those which are included in the preferred stochastic frontier model in Battese and Tessema (1993). However, Battese and Tessema (1993) assume that the parameters of the stochastic frontiers are a linear function of time of observation only. In this study, the coefficients of the stochastic frontiers are specified to be linear functions of the age and formal schooling of the primary decision maker (called the farmer) in the farming operation, in addition to the time of observation. This model implies that the parameters of the production frontiers may change linearly over time, which implies that not only the level of production may change but also the elasticities of production of the different inputs. Further, it is hypothesized that the coefficients of the frontier may be related to the age and formal education of the farmers involved. Thus the stochastic frontier production function (1)-(3) has time-varying technical inefficiencies, and farmer-specific and time-varying coefficients of the explanatory variables.

In an investigation of the sources of inefficiency in the Indonesian weaving industry, Pitt and Lee (1981) found that age had a significant contribution to inefficiency. Aside from other farmer- and farm-specific variables, Kalirajan (1981), Kalirajan and Shand (1989), Ali and Flinn (1989) and Kumbhakar, Biswas and Bailey (1989) identified farmers' level of education as a determinant of technical efficiency. Battese and Coelli (1993) estimate a frontier model in which the technical inefficiency effects, the U_{it}'s, are specified to be a function of the farmer-specific variables, age and education, and the year of observation. Huang and Liu (1993) propose a non-neutral stochastic frontier model in which the stochastic frontier is a transcendental logarithmic function of input variables and the technical inefficiency model is a function of some firm-specific variables and interactions among these firm-specific variables and the input variables.

The full model, defined by equations (1) and (2), involves interactions among the farmer-specific variables and time of observation and the explanatory variables of the stochastic frontier, as follows:

$$
\begin{aligned}
\ln Y_{it} = {} & \beta_0 + \alpha_0(Age_{it}) + \delta_0(Educ_{it}) + \varepsilon_0(Year_{it}) \\
& + \beta_1 \ln(Land_{it}) + \alpha_1(Age_{it})\ln(Land_{it}) + \delta_1(Educ_{it})\ln(Land_{it}) \\
& + \varepsilon_1(Year_{it})\ln(Land_{it}) \\
& + \beta_2 \ln(Labour_{it}) + \alpha_2(Age_{it})\ln(Labour_{it}) + \delta_2(Educ_{it})\ln(Labour_{it}) \\
& + \varepsilon_2(Year_{it})\ln(Labour_{it}) \\
& + \beta_3 \ln(Bullock_{it}) + \alpha_3(Age_{it})\ln(Bullock_{it}) + \delta_3(Educ_{it})\ln(Bullock_{it}) \\
& + \varepsilon_3(Year_{it})\ln(Bullock_{it}) \\
& + \beta_4 \ln(Cost^*_{it}) + \alpha_4(Age_{it})\ln(Cost^*_{it}) + \delta_4(Educ_{it})\ln(Cost^*_{it}) \\
& + \varepsilon_4(Year_{it})\ln(Cost^*_{it}) \\
& + \beta_5\left(\frac{IL_{it}}{Land_{it}}\right) + \alpha_5(Age_{it})\left(\frac{IL_{it}}{Land_{it}}\right) + \delta_5(Educ_{it})\left(\frac{IL_{it}}{Land_{it}}\right) \\
& + \varepsilon_5(Year_{it})\left(\frac{IL_{it}}{Land_{it}}\right) \\
& + \beta_6\left(\frac{HL_{it}}{Labour_{it}}\right) + \alpha_6(Age_{it})\left(\frac{HL_{it}}{Labour_{it}}\right) + \delta_6(Educ_{it})\left(\frac{HL_{it}}{Labour_{it}}\right) \\
& + \varepsilon_6(Year_{it})\left(\frac{HL_{it}}{Labour_{it}}\right) + V_{it} - U_{it} \, . \qquad (4)
\end{aligned}
$$

This model is clearly related to the Huang and Liu (1993) model in that the combined model includes the inputs, the firm-specific variables and interactions among the inputs and the firm-specific variables. If the parameters of the interactions are not all equal to zero, then our model (4) is a non-neutral frontier, as defined by Huang and Liu (1993). However, in the derivation of the full frontier model (4), the α-, δ- and ε-parameters are not considered to be associated with technical inefficiencies of farmers.

Maximum-likelihood estimation of the parameters of the model, as defined by equations (4) is obtained using the program, FRONTIER 2.0 (see Coelli, 1991, 1992). The parameters associated with the distributions of the V_{it}- and U_{it}-random variables are estimated in terms of the parameters, σ_S^2 and γ, where $\sigma_S^2 \equiv \sigma_V^2 + \sigma^2$ and $\gamma \equiv \sigma^2/\sigma_S^2$. As noted in Battese and Coelli (1992), the parameter, γ, has possible values between 0 and 1, which implies some advantages for obtaining the maximum-likelihood estimates. This parameterization for the stochastic frontier production function is proposed in Battese and Corra (1977).

In the estimation of the frontier model, defined by equations (1)-(4), there are five special cases which are associated with the inefficiency effects, U_{it}. These models are:

- Model 1 is the full stochastic frontier production function with time-varying inefficiency effects, defined above;
- Model 2 is the traditional average response function (i.e., the special case of Model 1 in which $\gamma = \mu = \eta = 0$);
- Model 3 is the stochastic frontier model in which the inefficiency effects are time-invariant and are truncations of the $N(0,\sigma^2)$ distribution (i.e., $\mu = \eta = 0$);
- Model 4 is the stochastic frontier production function in which the inefficiency effects have half-normal distribution (i.e., $\mu = 0$); and
- Model 5 is the stochastic frontier production function in which the inefficiency effects are time-invariant (i.e., $\eta = 0$).

4 Estimated Stochastic Frontiers

Tests of hypotheses involving the parameters, defined in Models 1 to 5, are obtained by the use of the generalized likelihood-ratio test[5]. Empirical results for Model 1 for each village are presented in Table 2 and the corresponding tests of hypotheses are presented in Table 3.

For the Aurepalle data, there is not enough evidence to reject the null hypothesis, H_0: $\gamma = \mu = \eta = 0$. This implies that the traditional average response function is an adequate representation for the Aurepalle data. The same conclusion is obtained in Battese and Tessema (1993) for the case in which the production frontier has coefficients which are only a linear function of time. However, for the frontier model with time-invariant parameters, Tessema (1991) concludes that the hypothesis of no inefficiency effects in the model is rejected.

In the Shirapur case, the null hypothesis, H_0: $\gamma = \mu = \eta = 0$, is rejected, which implies that the traditional response function is not an adequate representation of the data. In addition, the other three hypotheses (i.e., H_0: $\mu = \eta = 0$; H_0: $\mu = 0$; and H_0: $\eta = 0$) are also rejected. This indicates that, given the specifications of the time-varying stochastic frontier with time-varying technical inefficiency effects, no sub-model for the inefficiency effects is an adequate representation for the Shirapur data.

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[5] The generalized likelihood-ratio test statistic is defined by $\chi^2 = -2ln[L(H_0)/L(H_1)]$, which has approximately a χ^2_ν distribution, where $L(H_0)$ and $L(H_1)$ are the values of the likelihood function of the restricted and unrestricted models, respectively, and ν is the difference between the number of parameters in the restricted and unrestricted models.

Table 2: Maximum-likelihood Estimates for Parameters of the Time-varying Stochastic Frontier with Time-varying Technical Inefficiency Effects for Farmers in Aurepalle, Shirapur and Kanzara[a]

		M.L. Estimates for		
Variable	Parameter	Aurepalle	Shirapur	Kanzara
Constant	β_0	0.64 (0.88)	0.12 (0.87)	-0.10 (0.87)
Age	α_0	-0.51 (0.58)	0.25 (0.24)	0.19 (0.28)
Education	δ_0	-0.12 (0.77)	-0.08 (0.10)	0.034 (0.076)
Year	ε_0	0.28 (0.64)	0.18 (0.12)	0.191 (0.084)
ln(Land)	β_1	-0.54 (0.70)	0.33 (0.28)	0.36 (0.41)
Age × *ln*(Land)	α_1	0.21 (0.13)	-0.007 (0.077)	0.051 (0.089)
Educ × *ln*(Land)	δ_1	0.04 (0.20)	0.025 (0.053)	-0.009 (0.022)
Year × *ln*(Land)	ε_1	-0.09 (0.15)	-0.047 (0.026)	-0.087 (0.028)
ln(Labour)	β_2	1.77 (0.77)	0.61 (0.27)	0.70 (0.54)
Age × *ln*(Labour)	α_2	-0.12 (0.12)	-0.023 (0.067)	0.04 (0.11)
Educ × *ln*(Labour)	δ_2	0.01 (0.20)	-0.003 (0.055)	-0.02 (0.29)

Table 2: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Year × *ln*(Labour)	ε_2	0.05 (0.11)	0.07 (0.20)	0.014 (0.037)
ln(Bullock)	β_3	-0.43 (0.66)	0.00 (0.31)	-0.16 (0.38)
Age × *ln*(Bullock)	α_3	-0.04 (0.11)	0.009 (0.054)	-0.029 (0.083)
Educ × *ln*(Bullock)	δ_3	-0.035 (0.057)	-0.042 (0.024)	0.029 (0.021)
Year × *ln*(Bullock)	ε_3	0.04 (0.14)	-0.001 (0.022)	0.044 (0.027)
ln(Cost*)	β_4	0.18 (0.31)	-0.04 (0.11)	0.029 (0.080)
Age × *ln*(Cost*)	α_4	-0.022 (0.057)	-0.006 (0.036)	0.002 (0.019)
Educ × *ln*(Cost*)	δ_4	-0.016 (0.015)	0.0076 (0.0073)	0.0019 (0.0047)
Year × *ln*(Cost*)	ε_4	0.0008 (0.0093)	-0.003 (0.015)	0.0015 (0.0071)
IL/Land	β_5	-1.45 (0.99)	0.67 (0.53)	1.44 (0.94)
Age × IL/Land	α_5	0.26 (0.33)	-0.091 (0.069)	-0.19 (0.17)

Table 2: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Educ × IL/Land	δ_5	0.05 (0.42)	0.069 (0.051)	0.011 (0.048)
Year × IL/Land	ε_5	-0.12 (0.33)	-0.061 (0.033)	-0.008 (0.043)
HL/Labour	β_6	-0.13 (0.98)	0.14 (0.94)	0.16 (0.56)
Age × HL/Labour	α_6	-0.066 (0.096)	-0.10 (0.12)	-0.033 (0.068)
Educ × HL/Labour	δ_6	-0.017 (0.020)	-0.041 (0.029)	0.004 (0.016)
Year × HL/Labour	ε_6	0.051 (0.018)	-0.041 (0.030)	-0.011 (0.021)
	σ_s^2	0.24 (0.34)	0.121 (0.067)	0.127 (0.016)
	γ	0.44 (0.79)	0.20 (0.45)	0.12 (0.11)
	μ	-0.40 (0.99)	-0.05 (0.66)	0.22 (0.14)
	η	-0.24 (0.74)	0.24 (0.28)	0.024 (0.075)
ln(Likelihood)		-118.728	-107.858	-107.308

[a] The estimated standard errors of the maximum-likelihood estimators are given below the corresponding estimates, correct to two significant digits, as calculated by the program, FRONTIER, 2.0.

Table 3: Tests of Hypotheses Associated with the Technical Inefficiency Effects in the Stochastic Frontiers for Farmers in Aurepalle, Shirapur and Kanzara

Null Hypothesis	Aurepalle		Shirapur		Kanzara	
	LLF[a]	χ^2 [b]	LLF	χ^2	LLF	χ^2
H_0: $\gamma = \mu = \eta = 0$	-120.077	2.70	-157.324	98.93*	-111.284	7.95*
H_0: $\mu = \eta = 0$	-120.091	2.73	-136.542	57.37*	-107.979	1.34
H_0: $\mu = 0$	-120.094	2.73	-110.503	5.29*	-107.749	0.88
H_0: $\eta = 0$	-119.842	2.23	-136.019	56.32*	-107.548	0.48

[a] LLF denotes the logarithm of the likelihood function for the sample observations, given the specifications of the frontier models involved.

[b] When the value of the χ^2-statistic is significant at the 5% level, the value has the asterisk, *, attached.

For the Kanzara farmers, the traditional response function does not adequately represent the data because the null hypothesis, H_0: $\gamma = \mu = \eta = 0$, is rejected. However, the null hypotheses, H_0: $\mu = \eta = 0$; H_0: $\mu = 0$; or H_0: $\eta = 0$, are not rejected. Furthermore, given that the frontier model with time-invariant inefficiency effects arising from the half-normal distribution (i.e., $\mu = \eta = 0$) is estimated, then the null hypothesis, H_0: $\gamma = 0$, is rejected, since the asymptotic χ^2-statistic is 6.61. This is significant at the 5% level (i.e., greater than the 95th percentile for the chi-square distribution with one degree of freedom). These tests imply that there are significant technical inefficiency effects in the stochastic frontier production function for Kanzara, but the inefficiency effects are time invariant and arise from the half-normal distribution.

Based on the tests above, the preferred models for the technical inefficiency effects are Model 2 for Aurepalle, Model 1 for Shirapur, and Model 3 for Kanzara.

The maximum-likelihood estimates for the parameters of the stochastic frontier functions for the preferred inefficiency models for each village are presented in Table 4. However, before discussing the estimates obtained, we consider some tests of hypotheses concerning the effects of the variables, age, education and year of observation, on the coefficients of the different variables in the stochastic frontier production functions. We consider a set of null hypotheses in which it is postulated that there are no joint or individual effects of these variables on the coefficients of the production frontiers. The specific null hypotheses involved and the corresponding test statistics are presented in Table 5. In each of the cases involved, we consider first that age, education and year of observation have no effects on any of the coefficients of the production frontiers (i.e., level of

Table 4: Maximum-likelihood Estimates for Parameters of the Frontier Production Functions with the Preferred Inefficiency Models for Aurepalle, Shirapur and Kanzara

		M.L. Estimates for		
Variable	Parameter	Aurepalle	Shirapur	Kanzara
Constant	β_0	0.56 (0.67)	0.12 (0.87)	-0.35 (0.97)
Age	α_0	-0.05 (0.22)	0.25 (0.24)	0.24 (0.29)
Education	δ_0	-0.11 (0.12)	-0.08 (0.10)	0.042 (0.077)
Year	ε_0	0.26 (0.10)	0.18 (0.12)	0.190 (0.088)
ln(Land)	β_1	-0.52 (0.33)	0.33 (0.28)	0.35 (0.38)
Age × *ln*(Land)	α_1	0.201 (0.062)	-0.007 (0.077)	0.053 (0.083)
Educ × *ln*(Land)	δ_1	0.037 (0.042)	0.025 (0.053)	-0.008 (0.021)
Year × *ln*(Land)	ε_1	-0.087 (0.032)	-0.047 (0.026)	-0.086 (0.028)
ln(Labour)	β_2	1.81 (0.40)	0.61 (0.27)	0.71 (0.50)
Age × *ln*(Labour)	α_2	-0.130 (0.065)	-0.023 (0.067)	0.05 (0.11)
Educ × *ln*(Labour)	δ_2	0.015 (0.045)	-0.003 (0.055)	-0.025 (0.029)

Table 4: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Year × *ln*(Labour)	ε_2	0.057 (0.034)	0.07 (0.20)	0.010 (0.036)
ln(Bullock)	β_3	-0.44 (0.36)	0.00 (0.31)	-0.14 (0.42)
Age × *ln*(Bullock)	α_3	-0.030 (0.066)	0.009 (0.054)	-0.037 (0.089)
Educ × *ln*(Bullock)	δ_3	-0.037 (0.031)	-0.042 (0.024)	0.029 (0.022)
Year × *ln*(Bullock)	ε_3	0.026 (0.037)	-0.001 (0.022)	0.047 (0.028)
ln(Cost*)	β_4	0.18 (0.11)	-0.04 (0.11)	0.024 (0.082)
Age × *ln*(Cost*)	α_4	-0.023 (0.019)	-0.006 (0.036)	0.004 (0.020)
Educ × *ln*(Cost*)	δ_4	-0.016 (0.012)	0.0076 (0.0073)	0.0026 (0.0047)
Year × *ln*(Cost*)	ε_4	0.0013 (0.0084)	-0.003 (0.015)	0.0010 (0.0070)
IL/Land	β_5	-1.46 (0.94)	0.67 (0.53)	1.45 (0.85)
Age × IL/Land	α_5	0.26 (0.13)	-0.091 (0.069)	-0.19 (0.16)

Table 4: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Educ × IL/Land	δ_5	0.044 (0.073)	0.069 (0.051)	0.007 (0.048)
Year × IL/Land	ε_5	-0.131 (0.058)	-0.061 (0.033)	-0.005 (0.043)
HL/Labour	β_6	-0.16 (0.47)	0.14 (0.94)	0.33 (0.57)
Age × HL/Labour	α_6	-0.058 (0.061)	-0.10 (0.12)	-0.057 (0.069)
Educ × HL/Labour	δ_6	-0.021 (0.026)	-0.041 (0.029)	0.003 (0.017)
Year × HL/Labour	ε_6	0.050 (0.025)	-0.041 (0.030)	-0.008 (0.023)
	σ_s^2	0.157 (0.091)	0.121 (0.067)	0.156 (0.023)
	γ	0	0.20 (0.45)	0.27 (0.12)
	μ	0	-0.05 (0.66)	0
	η	0	0.24 (0.28)	0
ln(Likelihood)		-120.077	-107.858	-107.979

Table 5: Tests of Hypotheses Associated with the Age, Education, Year of Observation and Labour Ratio Variables in the Stochastic Frontier Production Functions for Aurepalle, Shirapur and Kanzara

Null Hypothesis	Aurepalle		Shirapur		Kanzara	
	LLF[a]	χ^2[b]	LLF	χ^2	LLF	χ^2
Age, Education and Year Effects						
H_0: $\alpha_i = \delta_i = \varepsilon_i = 0$, $i = 0,1,\ldots,6$	-154.489	68.82*	-127.724	39.73*	-120.216	24.48
Age and Education Effects						
H_0: $\alpha_i = \delta_i = 0$, $i = 0,1,\ldots,6$	-133.195	26.24*	-116.821	17.93	-112.800	9.64
Age Effects						
H_0: $\alpha_i = 0$, $i = 0,1,\ldots,6$	-129.205	18.26*	-111.911	8.11	-110.539	5.12
Education Effects						
H_0: $\delta_i = 0$, $i = 0,1,\ldots,6$	-122.971	5.79	-116.161	16.61*	-109.102	2.25
Year Effects						
H_0: $\varepsilon_i = 0$, $i = 0,1,\ldots,6$	-146.302	52.45*	-117.694	19.67*	-115.675	15.39*
Labour Ratio						
$H_0 = \beta_6 = \alpha_6 = \delta_6 = \varepsilon_6 = 0$,	-125.658	5.58	-112.183	8.65	-109.326	2.70

[a] LLF denotes the logarithm of the likelihood function for the sample observations, given the specifications of the frontier models involved.

[b] When the value of the χ^2-statistic is significant at the 5% level, the value has the asterisk, *, attached.

production and elasticities). The second case considered is that age and education have no effects on any of the coefficients of the production frontier. Subsequently, we consider the hypotheses that age, education and year of observation, individually, have no effects on the levels of production and the elasticities of production.

The hypothesis that age, education and year of observation have no effects on production, (i.e., H_0: $\alpha_i = \delta_i = \varepsilon_i = 0$, $i = 0,1,\ldots,6$) is rejected for Aurepalle and Shirapur, but accepted in Kanzara. Thus we conclude that the stochastic frontier production function with constant coefficients over time, which are not influenced by age and education, is an adequate representation of the technology facing Kanzara farmers. However, for farmers in Aurepalle and Shirapur it is not reasonable to conclude that age, education and year of observation have no effects on the levels of production or the elasticities of production.

The null hypothesis that the age and education of the farmers have no effects on the coefficients of the frontier production functions (i.e., H_0: $\alpha_i = \delta_i = 0$, $i = 0,1,\ldots,6$) is rejected only for Aurepalle. Thus, for Shirapur, the null hypothesis that age and education have no joint effects on the coefficients of the production frontier is accepted.

The null hypothesis, that age has no effects on the stochastic frontier (i.e., H_0: $\alpha_i = 0$, $i = 0,1,\ldots,6$), is rejected for Aurepalle, but accepted for Shirapur and Kanzara. Further, the null hypothesis, that education, individually, has no effects on the coefficients of the production frontiers (i.e., H_0: $\delta_i = 0$, $i = 0,1,\ldots,6$), is rejected only for Shirapur. Finally, the hypothesis that the year of observation has no effects on the coefficients of the stochastic frontier production functions (i.e., H_0: $\varepsilon_i =$

0, $i = 0,1,\ldots,6$) is rejected for the three villages involved[6].

In addition to considering the effects of age, education and year of observation on the coefficients of the frontier production functions, we consider the matter of whether family and hired labour are equally productive in the agricultural operations of the three villages involved. In the context of the general frontier production function, defined by equation (4), the hypothesis of equal productivity of family and hired labour implies that the coefficients associated with the labour-ratio variable, HL/Labour, are zero. Further, given the specifications of equation (2), by which the coefficients of the labour ratio are related to age, education and year of observation of the farmers, the hypothesis of equal productivity of hired and family labour implies that the four parameters, β_6, α_6, δ_6 and ε_6, are simultaneously zero. Tests of this hypothesis are presented in the last section of Table 5 for the three villages involved, given the assumptions of the preferred inefficiency models for the respective villages, as estimated in Table 4. It is evident that the test statistic of the null hypothesis, H_0: $\beta_6 = \alpha_6 = \delta_6 = \varepsilon_6 = 0$, is not significant at the 5% level for any of the three villages. This implies that hired and family labour can be regarded as equally productive in Aurepalle, Shirapur and Kanzara, given the specifications of the frontier production functions involved.

On the basis of the above hypotheses tests, the preferred frontier models for the three villages are:

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[6] The same conclusions, as indicated in Table 5, are obtained when the null hypotheses involve testing if there are no age, education and year effects on only the elasticities of production (e.g., H_0: $\alpha_i = \delta_i = \varepsilon_i = 0$, $i = 1,2,\ldots,6$). Alternatively, this hypothesis is equivalent to stating that the stochastic frontier is a non-neutral model, cf. Huang and Liu (1993).

(i) For Aurepalle: the traditional average production function, involving no technical inefficiencies, where the coefficients of the explanatory variables are time varying and depend on the age of the farmers, but education effects are not significant;

(ii) For Shirapur: the stochastic frontier production function with time-varying technical inefficiencies and time-varying coefficients for the variables, but age and education have no effects[7];

(iii) For Kanzara: the stochastic frontier production function with time-invariant technical inefficiencies, which have half-normal distribution, but the coefficients of the explanatory variables are time invariant and do not depend on the age and education of the farmers[8].

The conclusion that years of formal education has no significant effect on production in the three villages contradicts the findings of Kalirajan (1981), Kalirajan and Shand (1989), Ali and Flinn (1989) and Kumbhakar, Biswas and Bailey (1989). The large proportion of farmers with no formal education may have resulted in insufficient variability in the data to detect any significant effects on production. However, as noted above, the effects

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[7] We conclude that the age and education effects are not present in the frontier, given that the null hypothesis that the coefficients associated with these characteristics are jointly zero. However, a test of the hypothesis that the coefficients associated with education only are zero would be rejected for Shirapur.

[8] We conclude that the coefficients of the frontier for Kanzara are time invariant and do not depend on age and education of the farmers because the test of the hypothesis, that the coefficients associated with these variables are zero, is not rejected. However, a test of the hypothesis that the coefficients of the frontier are time invariant, without considering age and education effects, would be rejected for Kanzara.

of education for farmers in Shirapur are significant if education is considered separately from age of the farmers.

The finding that hired and family labour are equally productive for the three villages in this study is consistent with results reported in Battese, Coelli and Colby (1989) but contradicts the result in Battese and Tessema (1993) for the Aurepalle data. However, the results for Shirapur and Kanzara are consistent with those in Battese and Tessema (1993).

Given the specifications of these preferred stochastic frontier production functions, the estimated parameters for the models involved are presented in Table 6. It is noted that the age of farmers has a negative effect on the level of production in Aurepalle but has a positive effect on the elasticity of land and negative effects on the elasticities of labour, bullock labour and cost of other inputs. Age of farmers has a positive effect on the productivity of irrigated land in Aurepalle.

The time-varying coefficients of the production frontiers for farmers in Aurepalle and Shirapur are such that the elasticities of land decrease over time, whereas the elasticities of labour increase over time for both villages. The elasticities of bullock labour and cost of inputs do not change in the same way over time in the villages of Aurepalle and Shirapur. Year of observation has a negative effect on the productivity of irrigated land in both of these villages.

The estimated coefficients associated with the proportion of irrigated land in the production frontier indicate that there are positive effects of irrigation on the production of farmers in Shirapur and Kanzara, but a negative effect in Aurepalle. This is a strange result for Aurepalle, in which there is considerable paddy production and increasing the proportion of irrigated land is expected to increase the value of output for the farmers

Table 6: Maximum-likelihood Estimates for the Preferred Frontier Production Functions for Aurepalle, Shirapur and Kanzara

		M.L. Estimates for		
Variable	Parameter	Aurepalle	Shirapur	Kanzara
Constant	β_0	0.32 (0.64)	0.55 (0.77)	0.80 (0.16)
Age	α_0	-0.49 (0.19)	0	0
Education	δ_0	0	0	0
Year	ε_0	0.283 (0.095)	0.12 (0.14)	0
ln(Land)	β_1	-0.53 (0.32)	0.38 (0.26)	0.039 (0.070)
Age × *ln*(Land)	α_1	0.201 (0.059)	0	0
Educ × *ln*(Land)	δ_1	0	0	0
Year × *ln*(Land)	ε_1	-0.075 (0.032)	-0.046 (0.037)	0
ln(Labour)	β_2	1.70 (0.35)	0.48 (0.19)	0.918 (0.088)
Age × *ln*(Labour)	α_2	-0.130 (0.061)	0	0
Educ × *ln*(Labour)	δ_2	0	0	0

Table 6: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Year × *ln*(Labour)	ε_2	0.063 (0.032)	0.066 (0.032)	0
ln(Bullock)	β_3	-0.43 (0.36)	-0.06 (0.22)	0.061 (0.069)
Age × *ln*(Bullock)	α_3	-0.021 (0.066)	0	0
Educ × *ln*(Bullock)	δ_3	0	0	0
Year × *ln*(Bullock)	ε_3	0.015 (0.036)	-0.006 (0.034)	0
ln(Cost*)	β_4	0.11 (0.11)	-0.042 (0.048)	0.050 (0.015)
Age × *ln*(Cost*)	α_4	-0.018 (0.019)	0	0
Educ × *ln*(Cost*)	δ_4	0	0	0
Year × *ln*(Cost*)	ε_4	0.0050 (0.0082)	-0.0030 (0.0073)	0
IL/Land	β_5	-0.89 (0.84)	0.59 (0.93)	0.36 (0.20)
Age × IL/Land	α_5	0.21 (0.11)	0	0

Table 6: *continued*

Variable	Parameter	M.L. Estimates for Aurepalle	Shirapur	Kanzara
Educ × IL/Land	δ_5	0	0	0
Year × IL/Land	ε_5	-0.109 (0.054)	-0.077 (0.074)	0
HL/Labour	β_6	0	0	0
Age × HL/Labour	α_6	0	0	0
Educ × HL/Labour	δ_6	0	0	0
Year × HL/Labour	ε_6	0	0	0
	σ_s^2	0.161 (0.057)	0.138 (0.084)	0.169 (0.026)
	γ	0	0.23 (0.45)	0.25 (0.12)
	μ	0	-0.11 (0.81)	0
	η	0	0.241 (0.055)	0
ln(Likelihood)=LLF		-128.454	-118.288	-122.742

involved.

Technical inefficiency of production in Shirapur declines over time, as indicated by a positive estimate of η of 0.241. Battese and Tessema (1993) obtain the same result with the production frontier in which the coefficients of the variables are time varying but do not depend on the age of the farmers.

Using the mean of age, years of formal education, and year of observation, the estimated elasticities of the inputs in the final preferred model are calculated and presented in Table 7. For the Aurepalle data, the elasticities for land, labour and input costs are estimated to be 0.15, 1.34 and 0.04, respectively. A negative estimate for the elasticity of 0.47 is obtained for bullock labour. This result is also reported in Battese and Tessema (1993) and in other studies [see Battese, Coelli and Colby (1989), Tessema (1991) and Battese and Coelli (1992)].

For Shirapur, elasticities for land and labour are estimated to be 0.14 and 0.822, respectively, but negative estimates of -0.091 and -0.057 are obtained for the elasticities for bullock labour and input costs, respectively. For Kanzara, all estimated elasticities are positive, the values being 0.039, 0.918, 0.061 and 0.050 for land, labour, bullock labour and input costs, respectively.

The returns-to-scale parameter for the agricultural production in Aurepalle, Shirapur and Kanzara are estimated to be 1.06, 0.81 and 1.07, respectively. Thus in Shirapur there appear to be decreasing returns to scale.

Table 7: Estimated Elasticities and Returns-to-Scale Parameters from the Preferred Stochastic Frontier Production Functions for Aurepalle, Shirapur and Kanzara, Evaluated at the Average Values of Age, Years of Education and Year of Observation

		Estimated Elasticities for		
Variable	Parameter[a]	Aurepalle	Shirapur	Kanzara
Land	β_{1t}	0.15 (0.64)	0.14 (0.45)	0.039 (0.070)
Labour	β_{2t}	1.34 (0.69)	0.822 (0.074)	0.918 (0.088)
Bullocks	β_{3t}	-0.47 (0.35)	-0.091 (0.067)	0.061 (0.069)
Costs	β_{4t}	0.04 (0.20)	-0.057 (0.019)	0.050 (0.015)
Returns-to-Scale		1.06	0.81	1.07

[a] The elasticity estimates for the inputs in the general frontier production function, defined by equations (1)-(2), are given by

$$\beta_{jt} = \beta_j + \alpha_j(\text{Age}_{it}) + \delta_j(\text{Educ}_{it}) + \varepsilon_j(\text{Year}_{it}), \quad j = 1,2,3,4,$$

where land, labour, bullock labour and costs of other inputs are represented by j = 1,2,3,4, respectively. These elasticities are estimated at the average values of appropriate characteristics involved in the production frontiers for the three villages.

5 Predicted Technical Efficiencies

Battese and Coelli (1988) define the technical efficiency of a given firm as the ratio of its mean production, given its realized technical inefficiency effect, to the corresponding mean production if the inefficiency effect was zero. Thus, the technical efficiency of the i^{th} firm at the t^{th} year of observation, denoted by TE_{it}, is defined for the particular frontier model as $TE_{it} = \exp(-U_{it})$.

Because the preferred production frontier for farmers in Aurepalle is the traditional average production function with no technical inefficiencies, then the farmers in Aurepalle are 100% technically efficient, given the technical knowledge available to them at the time of the panel study.

Given the preferred frontier models for farmers in Shirapur an Kanzara, the predictions for the technical efficiencies of the farmers in these two villages are presented in Tables 8 and 9, respectively. Technical efficiencies for farmers in Shirapur are presented for each year of observation involved because the preferred stochastic frontier production function has time-varying technical inefficiency effects.

From Table 8, we observe that there is a high variation of technical efficiencies of farmers in Shirapur. The lowest technical efficiency in the first year of observation is 0.140 (for Farmer 23). Farmer 27 has the highest technical efficiency among farmers throughout years involved in the period of study. Farmer 9 has the lowest technical efficiency among those observed at the last year of the panel. However, technical efficiencies increase during the ten-year period of observation with a mean of 0.481 in the first year and a mean of 0.899 in the last year of observation. During the tenth year of observation, the lowest technical efficiency is 0.623 and the highest is 0.983. This is comparable to the results presented in Battese

Table 8: Predicted Technical Efficiencies for Farmers in Shirapur from 1975-76 to 1984-85, Given the Specifications of the Preferred Stochastic Frontier Production Function Presented in Table 6

	Technical Efficiencies									
Farmer	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85
1	-	0.434	0.517	0.594	0.663	0.724	0.775	0.818	0.854	0.883
2	-	0.196	0.276	0.363	0.450	-	-	-	-	-
3	-	0.861	0.888	0.910	0.928	0.943	0.955	0.964	0.972	0.978
4	-	-	-	-	-	0.791	0.830	0.863	0.890	0.912
5	0.190	0.270	0.357	0.444	0.528	0.605	0.674	0.733	0.783	-
6	0.604	0.671	0.729	0.779	0.821	0.856	0.885	0.908	0.927	0.942
7	0.427	0.510	0.588	0.658	0.719	-	-	-	-	-
8	0.172	0.250	0.335	0.423	0.508	0.587	0.658	0.719	0.772	0.816
9	0.165	-	-	-	0.207	0.290	0.377	0.465	0.547	0.623
10	0.394	0.479	0.559	0.633	0.697	0.753	-	0.839	0.871	0.897
11	0.507	0.585	0.654	0.716	0.768	0.812	0.849	0.879	0.904	0.923
12	0.854	0.882	0.906	-	-	-	-	-	-	-
13	0.502	0.580	0.650	0.712	0.765	0.810	0.847	0.877	0.902	0.922
14	0.518	0.595	0.663	0.723	0.775	0.818	0.853	0.883	0.906	-
15	0.369	0.456	0.538	0.613	0.681	0.736	0.788	0.829	0.863	0.890
16	0.303	0.390	0.476	0.558	0.631	0.696	0.752	0.799	-	-
17	0.323	0.410	0.495	0.574	0.646	0.709	-	-	-	-
18	0.405	0.489	0.569	0.641	0.705	0.759	0.805	0.843	0.874	0.900
19	0.401	0.486	0.566	0.638	0.702	0.757	0.803	0.842	0.873	0.899
20	0.736	0.784	0.825	0.859	0.887	0.909	0.928	-	-	-
21	0.215	-	-	0.469	-	0.625	0.691	0.748	0.796	0.835
22	0.646	0.707	0.760	0.805	0.843	0.874	0.899	0.920	0.936	0.949
23	0.140	-	-	-	0.467	-	-	-	-	-
24	0.540	0.614	0.680	0.738	0.787	0.828	0.862	0.889	0.912	0.930
25	0.606	0.673	0.731	0.780	0.822	0.857	0.886	0.909	0.927	0.942
26	0.291	0.378	0.464	0.546	0.621	0.688	0.745	0.793	0.833	0.866
27	0.866	0.892	0.913	0.931	-	0.956	0.965	0.973	0.978	0.983
28	0.627	0.691	0.746	0.794	0.833	0.866	0.893	0.915	0.932	0.946
29	0.555	0.628	0.692	0.748	0.795	0.835	0.867	0.894	0.916	0.933
30	0.738	0.785	0.826	0.859	0.887	-	-	-	-	-
31	0.837	0.868	0.894	-	-	-	-	-	-	-
32	0.322	-	-	-	-	-	-	-	-	-
33	-	0.282	0.369	0.456	0.538	0.614	-	-	-	-
34	-	0.654	0.714	0.766	0.810	-	-	0.902	0.922	0.938
35	-	0.807	0.844	0.874	0.899	0.919	0.936	0.949	0.960	0.968
Mean	0.481	0.545	0.608	0.666	0.720	0.768	0.809	0.844	0.874	0.899

and Tessema (1993), with a mean of 0.57 in 1975-76 to a mean of 0.936 in 1984-85.

For Kanzara, the predicted time-invariant technical efficiencies of farmers range from 0.717 to 0.962, with a mean of 0.856, as noted in Table 9. Ten of the 33 farmers have predicted technical efficiencies greater than 0.90. On the other hand, eight of the farmers have predicted technical efficiencies less than 0.80. As observed in the preceding section, age of the farmers, level of formal education of the farmers and year of observation have no significant effect on the level of production. The results indicate a high level of technical efficiency of farmers in Kanzara.

6 Summary and Conclusions

This study considers the possible effects of characteristics of farmers on the production frontiers in three Indian villages using panel data from ICRISAT's Village Level Studies. The characteristics of farmers are assumed to influence the parameters of the stochastic frontier production functions and the technical inefficiency effects are assumed to be an exponential function of time.

The findings in the empirical study on the three villages are:

(i) For Aurepalle: the preferred model is the traditional average production function, involving no technical inefficiencies, but the coefficients of the explanatory variables are time-varying and depend on the age of the farmers, but education effects are not significant.

(ii) For Shirapur: the preferred model is the stochastic frontier production function with time-varying technical inefficiencies and time-varying coefficients for the variables, but age and education have no effects.

Table 9: Predicted Technical Efficiencies for Farmers in Kanzara, Given the Specifications of the Preferred Stochastic Frontier Function Presented in Table 6

Farmer	Technical Efficiencies
1	0.775
2	0.717
3	0.895
4	0.822
5	0.841
6	0.858
7	0.912
8	0.769
9	0.930
10	0.917
11	0.932
12	0.884
13	0.903
14	0.744
15	0.926
16	0.805
17	0.838
18	0.962
19	0.754
20	0.865
21	0.846
22	0.870
23	0.807
24	0.855
25	0.940
26	0.756
27	0.790
28	0.959
29	0.845
30	0.775
31	0.908
32	0.850
33	0.884
Mean	0.856

(iii) For Kanzara: the preferred model is the stochastic frontier production function with time-invariant technical inefficiencies, which have half-normal distribution, but the coefficients of the explanatory variables are time-invariant, and do not depend on the age and education of the farmers.

Given the specifications of the preferred stochastic frontier production functions, it is noted that the age of farmers has a negative effect on the level of production in Aurepalle but has a positive effect on the elasticity of land and a negative effect on the elasticities of labour, bullock labour and costs of other inputs. The age of farmers has no significant effect on the level of output or the elasticities of production of farmers in Shirapur and Kanzara.

Years of formal education has no significant effect on production in the three villages. Further, hired and family labour are found to be equally productive for the three villages.

The value of output varies significantly over time for farmers in Aurepalle and Shirapur, but not for farmers in Kanzara. The general level of production increases over time in Aurepalle and Shirapur. However, the elasticities of land decrease over time, whereas the elasticities of labour increase over time, for both Aurepalle and Shirapur. The elasticities of bullock labour and costs of inputs do not change in the same way over time in the villages of Aurepalle and Shirapur. Time has a negative effect on the productivity of irrigated land in both of these villages.

Technical inefficiency of production declined over time in Shirapur. The mean elasticities for land, labour and cost of other inputs are estimated to be positive in Aurepalle, whereas the elasticity of bullock labour is estimated to be negative. For Shirapur, the elasticities for land and labour are estimated to be positive, while negative elasticity estimates are obtained for bullock labour and costs of other inputs. All estimated elasticities in Kanzara are positive. Estimated returns to scale are not significantly different from unity in all the villages.

Given the technical knowledge available during the period of the panel survey, the farmers in Aurepalle are found to be fully technically efficient. However, the age of the farmers and year of observation are found to have a significant effect on the value of output of farmers in Aurepalle.

Yearly estimated technical efficiencies for farmers in Shirapur show a high variation within each year but technical efficiencies increase throughout the ten-year period of the panel study. Estimated technical efficiencies are observed to have a mean of 0.481 in the first year of observation and a mean of 0.899 in the last year. This implies that the technical inefficiencies of farmers in Shirapur declined significantly over time.

The technical efficiencies of farmers in Kanzara are found to be time invariant, with a range of 0.717 to 0.912 and a mean of 0.856. However, the age and level of formal education of the farmers and year of observation have no significant effect on the production levels of farmers in Kanzara.

These results suggest that, aside from the traditional inputs of production, the age of the farmer may have a significant effect on production, although it is only observed in one of the villages. However, although the age of farmers may indicate experience in farming, it does not reflect the number of years the farmer has been farming. Thus, years in farming may be a better variable in the production frontier for farmers in the three villages.

The large proportion of farmers who did not have any formal education in the three villages may be the cause for the education variable to have no significant effect on the coefficients of the production frontiers. The technical knowledge, which may be indicated by the exposure of farmers to extension services, may be an important variable to be considered in future analyses.

The development of further econometric models for stochastic frontier production functions involving other characteristics of farmers, in addition to the traditional inputs of production, is still a challenging endeavour for the analysis of the production of farmers in different agricultural enterprises.

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