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Economic analysis of technical, allocative and economic efficiency estimation in rice cultivation in Tamil Nadu - a stochastic frontier analysis

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BACKGROUND AND OBJECTIVES

Rice cultivation :

Rice growing heavily consumes fresh water, *i.e.*, it takes some 5000 liters of water to produce one kg of rice. When compared to all other crops, rice production is less efficient in the way it uses water. Wheat, for example, consumes 4000 m3/ha, while rice consumes 7650 m3/ha (Thomas Byrne, 2011). Increasing or at least sustaining the productivity is of paramount importance when water has been becoming a scarce resource on account of over exploitation to meet the multifarious demands in the order of preference. At the same time, the country's rice production has to be increased to feed the growing population and to sustain food security.

The present study seeks to analyse the economics of efficiency estimation in rice production under different systems of irrigation *viz.*, canal, well and tank irrigation conditions. The study attempts to compare farmers' responses with respect to efficiency in rice production depending upon the systems of irrigation in Tamil Nadu. The study helps to formulate suitable policy for effective management of irrigation both at micro and macro levels.

Objective of the study :

The general objective of the study is to assess the economics of efficiency estimation in rice production under different irrigation systems, *viz.*, canal, well and tank irrigation systems in Tamil Nadu. However, the specific objective is to measure the technical, allocative and economic efficiencies in rice cultivation under different irrigation systems.

RESOURCES AND METHODS

Sampling design :

The method used for collecting the primary data was multi-stage random sampling technique. In the first stage of sampling, all the districts in Tamil Nadu, which had the predominant source of irrigation, *viz.*, canal, tank and wells, were listed. Among the top five districts ranked based on the area under the particular source of irrigation in the year 2013-14, one district was randomly selected. Thus, Thanjavur district to represent canal irrigation, Sivagangai district to represent tank irrigation and Salem district to represent well irrigation were selected. In the second stage, one rice growing block was randomly selected from each of the selected district. In the third stage, 80 farmers from the selected block of each district, who cultivated rice through the major source of irrigation, *viz.*, canal, well and tank, of the selected district were selected randomly. Thus, the total sample size was 240.

Analytical techniques employed :

Measurement of technical, allocative and economic efficiencies :

The stochastic frontier production function for estimating farm level technical efficiency is specified as:

$$Yi = f(X_i, \beta) + \varepsilon_i \quad (1)$$

where i is the n^{th} observations, Y_i is output, X_i denotes the actual input vector of production function and β is the vector of parameters of production function and ε is the error term that is composed of two elements, that is

$$\varepsilon_i = V_i - U_i \quad (2)$$

where V_i is the symmetric disturbances assumed to be identically, independently and normally distributed as N $(0, \sigma_{Vi}^2)$ given the stochastic structure of the frontier. The second component U_i is a one sided error term that is independent of V_i and is normally distributed as $(0, \sigma_{Ui}^2)$, allowing the actual production to short fall below the frontier but without attributing all short falls in output from the frontier as inefficiency.

The farm-specific technical efficiency is defined in terms of observed output (Y_i) to the corresponding frontier output (Y_i*) using the available technology derived which is defined as follows:

$$TE_i = \frac{Y_i}{Y_i*} = \frac{E(Y_i / u_i, X_i)}{E(Y_i / u_i = 0, X_i)}$$

$$= E[\exp(-U_i)/\varepsilon_i] \quad (3)$$

TE takes values within the interval (0, 1), where 1 indicates a fully efficient firm.

The stochastic frontier cost functions model for estimating firm level overall economic efficiency is specified as:

$$C_i = g(Y_i, P_i, \alpha) + \varepsilon_i \quad (4)$$

where C_i represents total production cost, Y_i represents output produced, P_i represent cost of input, α represents the parameters of the cost function and the error term composed of two elements, that is:

$$\varepsilon_i = V_i + U_i$$

Here V_i and U_i are as defined earlier. However, because inefficiencies are assumed to always increase costs, error components have positive signs.

The firm specific economic efficiency (EE) is defined as the ratio of minimum observed total production cost (C*) to actual total production cost C which is defined as follows:

$$EE = \frac{C_i}{C_i*} = \frac{E(C_i / u_i, Y_i, P_i)}{E(C / u_i = 0, Y_i, P_i)} = E[\exp(-U_i)/\varepsilon_i] \quad (5)$$

Here EE takes values between 0 and 1.

Hence a measure of firm specific allocation efficiency (AE) is thus obtained from technical and economic efficiencies estimated as:

$$AE = EE/TE \quad (6)$$

This means that $0 \leq AE \leq 1$

The Cobb-Douglas production function and cost function were employed to model production technology in this study. Here, the computer programme Front.4.1 was used for the analysis. It is noted that this computer program estimates the cost efficiency (CE), which is computed originally as the inverse of the equation (5). Hence, firm-level economic efficiency (EE) was obtained using the relationship:

$$EE = 1/\text{Cost efficiency (CE)} \quad (7)$$

This is the inverse of CE.

The stochastic frontier production function model specified for rice crop is given below.

$$\ln(Y) = \beta_0 + \beta_1(\ln X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \beta_4 \ln(X_4) + \beta_5 \ln(X_5) + \beta_6 \ln(X_6) + \beta_7 \ln(X_7) + \beta_8 \ln(X_8) + \beta_9 \ln(X_9) + (V_i - U_i)$$

where

Y = Yield of Paddy (Kg/ha)

X_1 = Seed (Kg/ha.)

X_2 = Human labour (man days/ha.)

X_3 = Machine power (hp hrs. /ha.)

X_4 = Farm yard manure (tonnes/ha)

X_5 = Plant protection chemicals (Rs/ha.)

X_6 = Nitrogen (Kg/ha.)

X_7 = Phosphorous (Kg/ha.)

X_8 = Potash (Kg/ha.)

X_9 = Irrigation (ha.cm.)

$\beta_0 = \ln \beta_0$ = Regression constant

$\beta_1, \beta_2, \beta_3, \beta_4, \ldots\ldots \beta_9$ = Elasticity co-efficients

The corresponding stochastic frontier cost function model specified for rice crop is given below :

$$\text{Ln}(C) = \alpha_0 + \alpha_1 (\ln P_1) + \alpha_2 \ln(P_2) + \alpha_3 \ln(P_3) + \alpha_4 \ln(P_4) + \alpha_5 \ln(P_5) + \alpha_6 \ln(P_6) + \alpha_7 \ln(P_7) + \alpha_8 \ln(P_8) + \alpha_9 \ln(P_9) + (V_i + U_i)$$

where

C = Total Cost of Production of Paddy (Rs/ha)

Y = Output produced (Kgs./ha.)

P_1 = Cost of Seed (Rs./ha.)

P_2 = Human labour charges (Rs./ha.)

P_3 = Machine power charges (Rs. /ha.)

P_4 = Cost of Farm yard manure (Rs./ha.)

P_5 = Cost of Plant protection chemicals (Rs./ha.)

P_6 = Cost of Nitrogen (Rs./ha.)

P_7 = Cost of Phosphorous (Rs./ha.)

P_8 = Cost of Potash (Rs./ha.)

P_9 = Irrigation charges (Rs./ha.)

$\alpha_0 = \ln \alpha_0$ = Regression constant

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \ldots\ldots \alpha_9$ = Parameters of the cost function to be estimated.

OBSERVATIONS AND ANALYSIS

The results obtained from the present study as well as discussions have been summarized under following heads :

Technical efficiency in rice farms :

Technical efficiency using stochastic production frontier using MLE method :

The technical efficiency of canal, well and tank irrigated rice cultivating farmers was estimated by using the stochastic frontier production function of Cobb-Douglas form using the MLE method. The stochastic frontier function analysis attempted in this study had the rice output kg/ha as the dependent variable and independent variables included were, human labour (man days/ha.), machine power (hp hrs./ha), seed rate (Kgs/ha), FYM (tonnes/ha), PPC (Rs./ha), nitrogen (Kgs/ha), phosphorus (Kgs/ha), potassium (Kgs/ha), and irrigation (ha.cm). The Maximum Likelihood Estimates (MLE) of the parameters of Cobb-Douglas stochastic frontier function were obtained using maximum likelihood procedures through FRONTIER 4.1 package and the results are presented in Table 1.

It could be concluded that the mean technical efficiency was 0.76, 0.75 and 0.71 for canal, well and tank irrigation system respectively. This showed that in the study region, the efficiency of the farmers were almost same for all the three systems of irrigation. Thus,

Table 1 : MLE estimates of stochastic frontier function for rice cultivation under different irrigation systems

Sr. No.	Variables	Thanjavur (Canal)			Sivagangai (Tank)			Salem (Well)		
		Co-efficient	Std. error	t value	Co-efficient	Std. error	t value	Co-efficient	Std. error	t value
Frontier production function										
1.	Constant	5.928*	0.704	8.426	4.830*	0.474	10.200	4.875*	0.637	7.654
2.	Human labour (man days/ ha.)	0.724*	0.129	5.619	0.284**	0.139	2.049	0.325*	0.049	6.680
3.	Machine power (hp. hrs/ha.)	-0.486***	0.249	-1.946	0.034 NS	0.043	0.804	0.080 NS	0.084	0.949
4.	Seed rate (kgs/ha.)	0.346***	0.181	1.910	0.076**	0.027	2.850	0.029 NS	0.041	0.701
5.	Farm Yard Manure (tonnes/ha.)	-0.232***	0.136	-1.710	-0.025 NS	0.026	-0.972	0.119**	0.040	2.951
6.	PPC (Rs/ha.)	0.034 NS	0.034	0.990	0.034 NS	0.120	0.282	0.163**	0.072	2.276
7.	Nitrogen (kgs/ha.)	-0.485*	0.113	-4.273	0.262*	0.059	4.441	0.076***	0.043	1.767
8.	Phosphorous (kgs/ha.)	0.028 NS	0.038	0.736	0.178*	0.043	4.128	0.094 NS	0.073	1.284
9.	Potash (kgs./ha)	0.149***	0.081	1.829	-0.019 NS	0.062	-0.316	-0.056 NS	0.057	-0.975
10.	Irrigation (ha.cm)	0.506*	0.117	4.293	0.318*	0.045	7.080	0.152**	0.071	2.142
Diagnosis statistics										
11.	Sigma-square (σ^2)	0.192*	0.016		0.072*	0.017		0.197*	0.065	
12.	Gamma (γ)	0.999*	0.0002		0.912*	0.064		0.752*	0.199	
13.	Log- likelihood	7.38			30.19			21.44		
14.	Mean technical efficiency	0.76			0.71			0.75		
15.	Mean technical inefficiency	0.24			0.29			0.25		
16.	Number of observations	80			80			80		

*, ** and *** indicate significance of values at P=0.1, 0.05 and 0.01, respectively NS=Non-significant

productivity can be increased by adoption of non-monetary inputs like timely sowing, maintaining optimum plant population, timely irrigation, efficient use of fertilizers and irrigation water, need based plant protection measures and timely harvesting of crop.

Distribution of farmers according to technical efficiency ratings :

Distribution of sample farmers according to different technical efficiency ratings of canal, well and tank irrigation systems were presented in Table 2 below.

It could be concluded that there was a variation in the level of technical efficiencies among the sample farmers who cultivated rice using different systems of irrigation. The sample farmers using canal system of irrigation for rice cultivation were technically efficient when compared to the farmers using tank and well system of irrigation for rice cultivation. This was due to the larger adoption of System of Rice Intensification technology among the sample farmers in Thanjavur district.

These results are important in that they provide detailed information to policy makers on the nature of production technologies used in farms. Thus, there was a scope to bridge the gap between the actual or realized and the potential output with the given technology by using available resources more efficiently.

Economic and allocative efficiencies using cost function using MLE method :

The economic efficiency of canal, well and tank

Table 2 : Distribution of farmers according to technical efficiency ratings **(Number of farmers)**

Sr. No.	Technical efficiency rating	Canal	Tank	Well
1.	<60%	11 (13.75)	15 (18.75)	8 (10.00)
2.	61% - 70%	12 (15.00)	20 (25.00)	13 (16.25)
3.	71% - 80%	26 (32.50)	26 (32.50)	25 (31.25)
4.	81% - 90%	22 (27.50)	15 (18.75)	30 (37.50)
5.	>90%	9 (11.20)	4 (5.00)	4 (5.00)
	Total	80 (100.00)	80 (100.00)	80 (100.00)

Figures in parentheses indicates percentage to total

Table 3 : MLE estimates of stochastic frontier cost function for rice cultivation under different irrigation systems

Sr. No.	Variables	Thanjavur (Canal)			Sivagangai (Tank)			Salem (Well)		
		Co-efficient	Std. error	t value	Co-efficient	Std. error	t value	Co-efficient	Std. error	t value
Frontier cost function										
1.	Constant	16.6592*	0.9931	16.7749	0.0134	1.7174	0.0078	12.8319*	0.9819	13.0684
2.	Total production (Kgs./ha)	-0.0051	0.9886	-0.0052	0.5228	0.3326	1.5719	0.4933*	0.1552	3.1785
2.	Human labour charges (Rs./ha.)	0.1516	1.042	0.1455	0.0346	0.0804	0.4303	0.0463	0.0437	1.0595
3.	Machine power charges (Rs./ha.)	0.3077	0.5916	0.5201	0.1050	0.1258	0.8347	-0.0150	0.0713	-0.2104
4.	Cost of Seed (Rs./ha.)	1.119	2.577	0.4342	0.0200	0.1681	0.1190	0.3944	0.8756	0.4504
5.	Cost of FYM (Rs./ha.)	-0.1127	0.1274	-0.8846	0.2854	0.2444	1.1678	0.0529	0.1718	0.3079
6.	Cost of PPC (Rs./ha.)	0.0006	0.4292	0.0014	0.0230	0.2355	0.0977	-0.0037	0.3176	-0.0116
7.	Cost of Nitrogen (Rs./ha.)	-0.1897	1.249	-0.1519	0.0334	0.0710	0.4704	-0.0417	0.0570	-0.7316
8.	Cost of Phosphorous (Rs./ha.)	0.1603	0.5305	0.3022	-0.0211	0.2539	-0.0831	0.1963	0.2787	0.7043
9.	Cost of Potash (Rs./ha.)	-0.1781	0.5845	-0.3047	0.0417	0.4562	0.0914	-1.9406*	0.4577	-4.2399
10.	Irrigation charges (Rs./ha.)	-2.0195*	0.6659	-3.0327	-0.0018	0.0219	-0.0822	0.0005	0.0322	0.0155
Diagnosis statistics										
11.	Sigma-square (σ^2)	22.68	0.594		16.95	1.69		7.348	0.774	
12.	Gamma (γ)	0.99	0.0058		0.99	0.00009		0.99	0.00008	
13.	Log- likelihood	-177.6			-88.02			-109.50		
14.	Economic efficiency (EE)	0.66			0.55			0.59		
15.	Allocative efficiency (EE/TE)	0.86			0.77			0.78		
16.	Number of Observations	80			80			80		

*, ** and *** indicate significance of values at P=0.1, 0.05 and 0.01, respectively NS=Non-significant

irrigated rice cultivating farmers was estimated by using the stochastic frontier cost function of Cobb-Douglas form using the MLE method. The stochastic frontier function analysis attempted in this study had the total cost of production of rice Rs./ha as the dependent variable and independent variables included were, rice output (Kgs./ha), human labour charges (Rs./ha.), machine power charges (Rs./ha), cost of seed rate (Rs./ha), cost of FYM (Rs./ha), cost of PPC (Rs./ha), cost of nitrogen (Rs./ha), cost of phosphorus (Rs./ha), cost of potassium (Rs./ha), and irrigation charges (Rs./ha). The Maximum Likelihood Estimates (MLE) of the parameters of Cobb-Douglas stochastic frontier function were obtained using maximum likelihood procedures through FRONTIER 4.1 package and the results are presented in Table 3.

Economic and allocative efficiencies :

The allocative efficiency was obtained by dividing the economic efficiency by technical efficiency. The results showed that, the economic and allocative efficiency of rice farms was higher in canal irrigated rice cultivation, followed by well and tank irrigated rice cultivations.

A high value for ã (0.99) would indicate the presence of significant inefficiency in the production of the crop. The estimate of ã would indicate that 99 per cent of the difference between the observed and frontier output was mainly due to the inefficient use of resources, which were under the control of the farmers. The remaining portion *i.e.*, 1 per cent was due to factors beyond the farmers' control. The average economic efficiency was estimated at 66 per cent in canal irrigated rice cultivation followed by well irrigated rice cultivation (59 %) and tank irrigated rice cultivation (55 %). Similarly, the average allocative efficiency was estimated at 86 per cent in canal irrigated rice cultivation followed by well irrigated rice cultivation (78 %) and tank irrigated rice cultivation (77 %). The results have clearly indicated that the selected farmers have better ability to achieve the maximum output with given inputs and also they used the inputs optimally in all the three selected districts.

Determinants of technical efficiency :

Factors determining the technical efficiency of rice cultivation :

The factors influencing the technical efficiency in rice cultivation under canal, well and tank irrigation systems have been identified using linear regression model. The dependent variable was technically efficiency estimated from the frontier production function. The explanatory variables such as age of the respondent, experience in farming, education level, family size and size of land holding were the variables included in the model. The co-efficients would reflect the impact of the explanatory variables on the technical efficiency attained by the sample farmers. It is evident that among the variables, age of respondents, education level, family size and size of land holding were having significant influence on the technical efficiency of sample farmers in canal irrigated rice cultivation, and age, education level, size of land holdings and farming experience of the respondents in tank irrigated rice cultivation.

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