Indian Journal of Science and Technology

Data Envelopment Analysis to Estimate Technical and Scale Efficiency of Farms in Periyar-Vaigai Irrigation System of Tamil Nadu, India

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Abstract

The present study is focused to analyse the technical and scale efficiency of farms in overall production of crops in Periyar-Vaigai irrigation system of Tamil Nadu. The input oriented Data Envelopment Analysis (DEA) was applied to estimate technical, pure technical and scale efficiency of the farms. A three stage random sampling procedure was used to select 270 sample respondents. The results of the study showed that there exist potential for increasing the profit further by 43 per cent in the farm holdings by following the best-practices of efficient farms. The study also found that about 47 per cent of the farms were not operating at optimal scale or nearer to optimal scale. The findings also indicated that all the farm inputs were used excessively by the sample respondents. The findings of the study could be helpful to farming community and policy makers to undertake necessary action to improve the current level of technical and scale efficiency in the study area.

Keywords: Technical Efficiency, Scale Efficiency, Pure Technical Efficiency, Constant Return to Scale, Variable Return to Scale, Input Slack, Data Envelopment Analysis.

1. Introduction

One of the main reasons for low productivity in agriculture all over the world is the inability of farmers to fully exploit the available technologies, resulting in lower efficiencies of production. Deshpande and Bhende [1] stated that the productivity increment is the only way out to fill the existing gap between demand and supply of food grain production, as the scope for further expansion of the area is very limited to meet out the requirement of ever increasing population in future. The productivity can be increased through introducing new technologies, adoption of existing technologies and efficient use of available resources. But, introducing new technologies is meaningless unless the existing technologies are used to their full potential [2]. Available literature indicates that farmers in developing countries fail to exploit the full potential of a technology and also make allocative errors [3, 4, 12, 5]. Thus, increasing the efficiency in production assumes greater significance in attaining potential output of the farms. Further, the examination of existing gap between the potential and actual yields on the farm, given the technology and resource endowment of farmers, would provide a better understanding of the yield gap along with the causative factors. Thus, technical efficiency (TE) is an indicator of productivity differences across farms. It may help in exploring the potentiality of the existing technology. Therefore, enhancing the technical efficiency at farm level is the key to meet the requirement of food grains for the growing population in near future. With this end in view, the present study focuses on measuring the efficiency of farms in Periyar-Vaigai irrigation system

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of Tamil Nadu state in India. The results of the study may help the policymakers in identifying appropriate policies and strategies to improve efficiency of farms.

2. Materials and Methods

2.1 Study Area and Data

Periyar-Vaigai command area was selected purposively as the universe of the study. After the overall improvement in the irrigation structure along the command area, it is witnessed that there is intensification of agriculture with adoption of new green revolution technologies and widespread changes in cropping pattern in the command area of this irrigation system, which led to significant increase in area of irrigated crops, especially paddy, sugarcane and banana as mono-cropping. Periyar-Vaigai command area sprawling around of five districts covering 31 blocks and 163 revenue villages. A three stage random sampling procedure was used to select the sample respondents. At first stage, the blocks in each of the district were arranged in the ascending order based on gross irrigated area in the year 2010–2011 and nine blocks were selected at random. At second stage, three villages from each of the block were selected at random. At third stage, ten farmers were selected at random from the each selected villages, thus constituting a total sample size of 270. The selected sample respondents were personally contacted and the required primary data were collected through personal interview method by using the pre tested interview schedule. The objectives and importance of the study were explained to the respondents briefly to solicit their co-operation. The cropping pattern among the sample farmers were comprised by the major crops such as paddy in kharif season, paddy in rabi season, sugarcane, banana, maize, cotton, sorghum, brinjal, tomato, chili and bhendi.

2.2 Tools of the Study

Technical efficiency is the ratio of output to input and it stands for the ability of a farm to produce maximal output from the given resources available in the farm. There are two approaches, which are used commonly, to estimate the technical efficiency. According to Farrell [6], these approaches are classified into two basic groups: parametric and non-parametric frontier models. Stochastic frontier production function is a parametric method which needs specification of a functional and distribution forms for its joint error structure [7]. Also, it allows the test of hypothesis concerning the goodness of fit of the model. Data Envelopment Analysis (DEA) is a non-parametric model. It does not necessitate assumptions about the production function and the error term distribution, and therefore potential misspecifications are avoided. Both models have their own demerits. Stochastic frontier model requires specification of technology, which may be restrictive in most cases and estimation of parameters and testing of hypothesis are not possible in DEA model.

2.2.1 Model specification

In present study, Data Envelopment Analysis model was used to estimate the technical, scale and return to scale. DEA uses linear programming to construct the efficient frontier with the best performing observations of the sample used, so that the frontier envelops all observations [8]. The distance from a farm to the frontier provides a measure of its efficiency. DEA also enables to assess under which returns to scale each farm operates and to calculate their scale inefficiency. Calculating efficiency under the assumption of constant returns to scale (CRS) gives the '*overall technical efficiency*' score, while assuming variable returns to scale (VRS) allows calculating one component of this total efficiency score, namely the '*pure technical efficiency*'. The latter captures the management practices, while the residual between total technical efficiency and pure technical efficiency shows whether the farm operates under optimal farm size. This residual is called '*scale efficiency*'. Estimated efficiency scores are ranging from 0 to 1. This means that a farm is operating under fully efficient condition when the efficiency score is one. Thus, the input oriented DEA (minimizing input use to obtain a particular output level) was used to estimate both constant returns to scale (CRS) and variable returns to scale (VRS) models. Under the assumption of constant returns to scale, the following input oriented linear programming model was used to measure the overall technical efficiency of farms [9]:

$$\begin{aligned} &\mathrm{Min}_{\theta,\lambda}\ \theta \\ &\text{Subject to} \\ &\quad -y+Y\lambda \geq 0 \\ &\quad \theta x_i - X\lambda \geq 0 \\ &\quad \lambda \geq 0 \end{aligned} \tag{1}$$

where,

y_i is a $m \times 1$ vector matrix of output for i[th] farm,

x_i is a $k \times 1$ vector matrix of inputs for i[th] farm,

Y is a $n \times m$ output matrix for 'n' number of farms,

X is a $n \times k$ input matrix for 'n' number of farms,

θ is an effecie ncy score, it is a scalar whose value would be the efficiency measure for each 'i' farm and it ranges from 0 to 1. If $\theta = 1$, then the farm would be efficient; otherwise, the farm would be below the efficient level, and

λ is a $n \times 1$ vector of matrix which provides the optimum solution. The λ values are used as weights in the linear combination of other efficient farms for an inefficient farm, which influences the projection of the inefficient farms on the calculated frontier.

This CRS is applicable only when all the firms are operating under the optimum scale. But, all firm are not able to operate under optimum condition due to imperfect competition and constraints on finance, etc. So, the estimation under CRS model will results in measure of technical efficiency which are confounded by scale efficiency. The use of the VRS specification will permit the calculation of technical efficiency devoid these scale effects. Thus, the VRS model to measure the pure technical efficiency is specified as the following linear programming model [10]:

$$\begin{aligned}&\mathrm{Min}_{\theta,\lambda}\ \theta\\&\text{Subject to}\\&\quad -y+Y\lambda \geq 0\\&\quad \theta x_i - X\lambda \geq 0\\&\quad \lambda \geq 0\\&\quad N_1\lambda = 1\end{aligned} \tag{2}$$

where, N_1 is a $n \times 1$ vector matrix of ones.

In addition, the technical efficiency obtained from the CRS model can be decomposed into two components, one is due to scale inefficiency and one due to pure technical inefficiency. Then difference between the efficiency score estimated from the CRS and VRS gives the scale inefficiency, indicating that return to scale can be increasing or decreasing [11]. The scale efficiency of individual farm was estimated by working out the ratio between technical efficiency scores of CRS and VRS models by following procedure mentioned below:

$$\theta_s = \theta_{CRS}(X_K, Y_K) / \theta_{VRS}(X_K, Y_K) \tag{3}$$

where,

$\theta_{CRS}(X_K, Y_K)$ = Technical efficiency under CRS model,

$\theta_{VRS}(X_K, Y_K)$ = Technical efficiency under VRS model and

θ_s = Scale efficiency.

It is essential to note that model which is specified for VRS in Equation (2) does not indicate whether the firm is falling in the increasing or decreasing returns to scale region [9]. The scale efficiency in Equation (3) is equal to one and confirms that the farm is operating under constant returns to scale. However, increasing or decreasing returns may occur when θ_s is less than one. So, in order to understand the nature of scale inefficiency, another problem of linear programming is necessary to replace the convexity constraint $N_1\lambda = 1$ in model (2) with $N_1\lambda \leq 1$ and $N_1\lambda \geq 1$ for the models of non-increasing returns and non-decreasing returns, respectively. Thus, the following models could also be employed for the measurement of the nature of efficiency.

Non-increasing returns:

$$\begin{aligned}&\mathrm{Min}_{\theta,\lambda}\ \theta\\&\text{Subject to}\\&\quad -y+Y\lambda \geq 0\\&\quad \theta x_i - X\lambda \geq 0\\&\quad \lambda \geq 0\\&\quad N_1\lambda \leq 1\end{aligned} \tag{4}$$

Non-decreasing returns:

$$\begin{aligned}&\mathrm{Min}_{\theta,\lambda}\ \theta\\&\text{Subject to}\\&\quad -y+Y\lambda \geq 0\\&\quad \theta x_i - X\lambda \geq 0\\&\quad \lambda \geq 0\\&\quad N_1\lambda \geq 1\end{aligned} \tag{5}$$

All the models given in previous section 3.2 were solved for each individual sample farms. All the crops cultivated by the all farmers were selected for the analysis. The inputs and output variables which were used for the DEA analysis are furnished in Table 1. The sum of the net income from each crops which was cultivated by the individual farmer were taken as the output variable of the DEA model in Rupees per farm. The crops such as kharif season paddy, rabi paddy, sugarcane, banana, cotton, maize, sorghum, brinjal, tomato, bhendi, chili and groundnut were cultivated by sample farms in the study area. Man labour in days, woman labour in days, nitrogen in kg, phosphorus in kg, potash in kg, machine labour in hours, farm yard manure in tonnes, cost of plant protection chemicals, irrigation water in ha mm, working capital and seed material cost in Rupees Rupees which were used by the farmers in production of different crops were taken as the inputs per farm.

3. Result and Discussion

3.1 Overall Technical Efficiency, Pure Technical Efficiency and Scale Efficiency

The results of the DEA of farms in the study area are given in Table 2. About 39 per cent of the sample farms were falling under the efficiency group (above 90 per cent) with the assumption of constant return to scale (CRS), whereas sample farms falling under least efficiency group (below 50 per cent) constitutes only 50.74 per cent of sample farms. This finding indicated that the most of the farms in the study area were not technically efficient with respect to input usage in crop production. Moreover, the overall technical efficiency of sample farms was ranging from 0.07 to 1.00 with mean efficiency score of 0.57. Similarly, the pure technical efficiency score was ranging from 0.11 to 1.00 with mean efficiency score of 0.66 and scale efficiency score was ranging from 0.27 to 1.00 with mean efficiency score of 0.86. Thus, the mean level of overall technical inefficiency was estimated as 43 per cent. This result succinctly brought out the fact that the farmers were not utilizing their production resources efficiently and also indicating that they were not obtaining maximal output from the given level of inputs available with them. In other words, technical efficiency among the sample farms can be increased by 43 per cent through adoption of best farm practices of efficient farms. In the case of scale efficiency, about 53 per cent of farms either performed at the optimum scale or were close to the optimum scale (farms having scale efficiency values equal to or more than 0.90). The decomposition of overall technical efficiency is given in Figure 1. As shown in the figure, pure technical inefficiency accounts for 34 per cent and scale inefficiency accounts for 12 per cent in overall technical efficiency among the farms.

Table 1. Description of the Input and Output Variables used in the DEA analysis

S.No.	Variables	Units (per farm)
I.	**Output Variable (Y)**	
1.	Profit	Rupees
II.	**Input Variables (Xi)**	
1.	Manures	Tonnes
2.	Nitrogen	Kg
3.	Phosphorus	Kg
4.	Potash	Kg
5.	Machine Labour	Hours
6.	Woman Labour	Man days
7.	Man Labour	Man days
8.	Cash Requirement for Plant Protection chemicals	Rupees
9.	Working Capital Requirement	Rupees
10.	Water Requirement	ha mm
11.	Seed material cost	Rupees

3.2 Scale of Operation of Farms

It is important to know about the number of farmers are operating in three regions of production scale such as optimal scale, sub-optimal scale and supra-optimal scale. As shown in the Figure 2, of the total sample farmers, 58 per cent are operating under sub-optimal situation, 30 per cent are operating supra-optimal scale and 12 per cent are operating at optimal scale condition. The results of the distribution of scale of operations in the production revealed that the about 58 per cent of the farmers had the scope to increase production by decreasing the input cost and about 30 per cent of famers could increasing their technical efficiency by reducing the production level.

Table 2. Efficiency level and summary statistics of overall technical efficiency, pure technical efficiency and scale efficiency of farms

Efficiency level	CRSTE	VRSTE	SE
Below 0.50	137	98	32
	(50.74)	(36.30)	(11.85)
0.50–0.60	20	20	10
	(7.41)	(7.41)	(3.70)
0.60–0.70	36	23	26
	(13.33)	(8.52)	(9.63)
0.70–0.80	25	90	24
	(9.26)	(7.41)	(8.89)
0.80–0.90	13	17	36
	(4.81)	(6.30)	(13.33)
Above 0.90	39	92	142
	(14.44)	(34.07)	(52.59)
Total No. of farmers	270	270	270
Mean	0.57	0.66	0.86
Standard Deviation	0.27	0.27	0.18
Minimum	0.07	0.11	0.27
Maximum	1	1	1

Note: Figures in parentheses are percentage to total farmers; CRSTE- Technical Efficiency under Constant Return to Scale; VRSTE- Technical Efficiency under Variable Return to Scale; SE - Scale Efficiency.

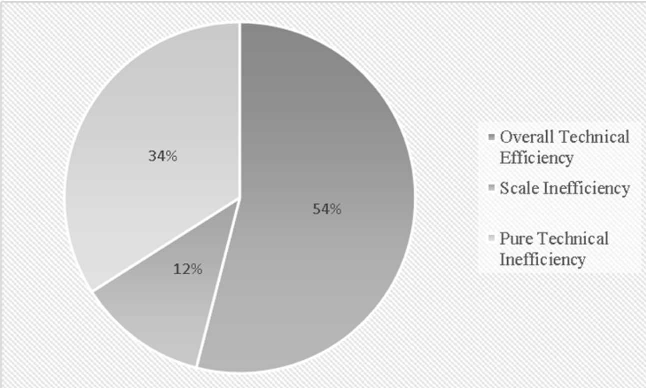

Figure 1. Percentage of pure and scale inefficiency in overall technical efficiency.

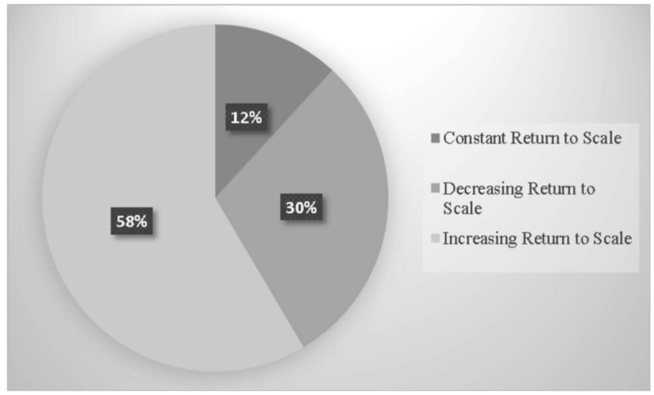

Figure 2. Distribution of scale of operation of farms.

3.3 Input slacks and Number of Farms Using Excess Inputs

The mean input slacks and excess input use percentages are given in Table 3. Since a slack indicates excess of an input, a farm can reduce its expenditure on this input by the amount of slack without reducing its output. Almost all the inputs were used excessively and the greatest slacks was observed in usage of farm yard manure use followed by potash, cost for plant protection, machine hours, nitrogen, woman labour, working capital, man labour, seed cost, water requirement and phosphorus usage. Moreover, inputs such as machine labour, woman labour, man labour, manure usage, nitrogen, potash and working capital were used excessively by more than 50 per cent of the farmers and phosphorus, water, seed cost and cost of plant protection chemicals were used excessively by only less than 50 per cent of the total farmers.

Table 3. Mean input slack and number of farmers using inputs excessively

S. No.	Inputs	Mean Input Usage	Mean Input Slack	No. of farmers using inputs excessively
1	2	3	4	5
1	Machine labour in hours/ha	12.09	4.36 (36.06)	195 (72.22)
2	Woman labour in days/ha	152.62	45.62 (29.89)	206 (76.30)
3	Man labour in days/ha	57.95	14.55 (25.11)	168 (62.22)
4	Manure in tonnes/ha	7.18	3.24 (45.13)	175 (64.81)
5	Nitrogen in kg/ha	179.24	57.76 (32.22)	216 (80.00)
6	Phosphorus in kg/ha	94.62	9.91 (10.47)	83 (30.74)
7	Potash in kg/ha	119.47	43.47 (36.39)	213 (78.89)
8	Water requirement in ha mm/ha	1815.19	204.14 (11.25)	112 (41.48)
9	Seed material cost in Rs./ha	7660.16	1501.94 (19.61)	88 (32.59)
10	Working capital in Rs./ha	66339.01	17538.69 (26.44)	225 (83.33)
11	Cost of plant protection chemicals in Rs./ha	1112.09	404.02 (36.33)	112 (41.48)

Note: Figures in parentheses in column 4 are percentage to mean input usage and figures in parentheses in column 5 are percentage to total farmers.

4. Conclusion

The results of the study showed that the mean technical efficiency of the farms indicated that there exist still a potential of 43 percent for increasing the profit of the farmers, if the production gap between the average and the best-practice farmers is narrowed. The study, also, showed that more than 50 percent of the farmers have scale efficiency which indicated that majority of farmers are not operating at the optimal scale and these farmers are operating very far away from the efficiency frontier. Also, the overall technical inefficiency among the farmers was attributed more to scale inefficiency than to the pure technical inefficiency. Moreover, it is important to note that all the inputs were used excessively by the sample farmers in the study region.

5. References

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