Journal of Agricultural Science; Vol. 5, No. 8; 2013
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Estimation of Technical, Scale and Economic Efficiency of Paddy Farms: A Data Envelopment Analysis Approach

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Received: March 2, 2013 Accepted: April 24, 2013 Online Published: July 15, 2013

doi:10.5539/jas.v5n8p243 URL: http://dx.doi.org/10.5539/jas.v5n8p243

Abstract

The present study attempted to analyse the efficiency level of paddy farms in Madurai district of Tamil Nadu state in India. The input oriented Data Envelopment Analysis (DEA) was employed to estimate technical, pure technical, scale, allocative and economic efficiency in the selected paddy farms. The results of the study showed that there exist potential for increasing the paddy output further by 20 percent in the farm holdings by following the best-practices of efficient farms. The study also revealed that 36 percent of the farm were operating at optimal scale and more than seventy per cent of the farms were operating below 50 percent of allocative and economic efficiency levels. The findings also indicated that all the farm inputs were used excessively by the sample farms; the excessive use of nitrogen and women labour was found in the case of fifty percent of the sample farms.

Keywords: technical efficiency, pure technical efficiency, scale efficiency, allocative efficiency, economic efficiency, data envelopment analysis

1. Introduction

Paddy is an important cereal crop consumed by most of the people across the globe and its cultivation provides livelihood security for more than two billion people. Paddy is the major food grain consumed in most of the Indian states and plays a major role in Indian economy. The area under paddy has increased from 31.29 million hectares in 1953-54 to 42.56 million hectares in 2010-11. Similarly, the paddy productivity increased from 902 kg/ha to 2240 kg/ha during the same period. As per 2010-11 statistics, paddy accounted for 33.85 per cent of the total area under food crops and also constituting 42.79 per cent of total area under cereal crops.

However, in the last 20 years, there was sluggishness in further increment of yield and the expansion of area under paddy in India. This sluggishness in the production of paddy would be due to inadequate water for irrigation and the increasing cost of farm inputs. Inter-regional fluctuations in production and productivity of paddy was observed with stagnating yields and ever increasing input costs across India. This increasing cost of inputs would create a situation where farmers may be disinterested to continue paddy cultivation as a profitable enterprise.

It is estimated that India will have to produce more paddy to meet the growing demand of 130 million tonnes of milled rice in the year 2030. Deshpande and Bhende (2003) 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 (Kalirajan et al., 1996). Available literature indicates that farmers in the developing countries fail to exploit the full potential of a technology and also make allocative errors (Kalirajan & Shand, 1989; Bravo-Ureta & Evenson, 1994; Shanmugan & Palanisami, 1994; Sharma & Datta, 1997). 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.

The yield gap of paddy is 40 per cent, even though many technologies are available currently to raise the yield of rice in India. In order to minimize the yield gap of paddy, the technological, infrastructural, social and policy-related constraints have to be removed. With this end in view, the present study focuses on measuring the efficiency of paddy production at farm level in Madurai district of Tamil Nadu state in India. Apart, the difference in efficiency across farms will be explained, which, in turn, may help the policymakers in identifying appropriate policies and strategies to improve efficiency of paddy production.

According to 2008-09 statistics, Tamil Nadu state accounts for 4.24 per cent of the total area under paddy in the country and 5.17 per cent of total production. The area under paddy in Tamil Nadu is almost stagnating over the years while the production and productivity of paddy is exhibiting significant variation over the years along with inter district fluctuations. The total paddy area in Triennium Ending (TE) 2009-10 is 18.55 lakh hectares. The season wise distribution of area under paddy pertaining to kuruvai, samba and navari seasons in 2009-10 indicated that kuruvai paddy (April-July) accounted for 16.61 per cent (3.08 lakh ha) and samba paddy (Aug.-Nov) accounted for 76.54 per cent (14.20 lakh ha) and navarai paddy (Dec.-March) accounted for 6.84 per cent (1.27 lakh ha).

Paddy productivity in Tamil Nadu has always been the above the national average. For instance, the average yield of paddy in the state was 2510 kg/ha during 2008-09 which was 324 kg/ha higher than the national average of 2186 kg/ha. The average productivity of paddy ranged from 2308 kg per ha to 3541 kg/ha in the last decade.

2. Materials and Methods

2.1 Study Area and Data

Madurai district was selected as the universe of the study, since the district is covered under Periyar-Vaigai irrigation system and it is one of the prominent district of Tamil Nadu, where in, paddy is extensively cultivated. A three stage random sampling method was adopted to select the sample respondents. At the first stage, all the blocks in Madurai districts were arranged in the ascending order based on the area cultivated under paddy for the year 2010-11 and three blocks namely Vadipatti, Alanganallur and Madurai East blocks were selected at random. Using the same criterion, three revenue villages from each of the selected blocks were selected at random, constituting nine revenue villages at second stage. At the third stage, using the same criterion, 10 farmers were selected from each of the selected nine revenue villages at random, thus constituting a total sample size of 90 farmers. The primary data on yield, input use pattern, cost of cultivation for paddy pertaining to the agricultural year 2010-11 were collected by personal interview method, using a pre -tested interview schedule along with the secondary information about the study region.

2.2 Analytical Framework

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 (1957), 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 (Coelli & Battese, 1996). 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 economic efficiencies. 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 (Charnes et al., 1978). 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 paddy farms (Coelli et al., 1998):

$\text{Min}_{\theta,\lambda}\ \theta$

Subject to

$$
\begin{aligned}
-y+Y\lambda &\geq 0 \\
\theta x_i - X\lambda &\geq 0 \\
\lambda &\geq 0
\end{aligned}
\tag{1}
$$

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 efficiency 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 (Banker, Charns, & Cooper, 1984):

$\text{Min}_{\theta,\lambda}\ \theta$

Subject to

$$
\begin{aligned}
-y+Y\lambda &\geq 0 \\
\theta x_i - X\lambda &\geq 0 \\
\lambda &\geq 0 \\
N_1\lambda &= 1
\end{aligned}
\tag{2}
$$

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 (Färe & Grosskopf, 1994). 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:

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

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 (Coelli et al., 1998). 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:

$Min_{\theta,\lambda}\ \theta$

Subject to

$$-y+Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$\lambda \geq 0$$
$$N_1\,\lambda \leq 1 \tag{4}$$

Non-decreasing returns:

$Min_{\theta,\lambda}\ \theta$

Subject to

$$-y+Y\lambda \geq 0$$
$$-y+Y\lambda \geq 0$$
$$-y+Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$-y+Y\lambda \geq 0$$
$$\lambda \geq 0$$
$$N_1\,\lambda \geq 1 \tag{5}$$

Besides these efficiency measures, allocative efficiency (AE) and economic efficiency (EE) were estimated to measure the farms' ability to allocate farm inputs optimally with their given respective input prices. The following linear programming model was used to estimate the economic efficiency of the firms:

$Min,\ _{\lambda,xi*}\ w_i'\ x_i*$

Subject to

$$-yi + Y\lambda \geq 0,$$
$$x_i* - X\lambda \geq 0$$
$$N_1'\lambda = 1$$
$$\lambda \geq 0, \tag{6}$$

where, w_i is vector of input price of i^{th} firm and x_i* (which is calculated by LP) is the cost-minimizing vector of input bundles of i^{th} farm, given the input price w_i and the output levels y_i. The economic efficiency for firm 'i' was then solved by the following computation:

$$EE = w_i'x* / w_i'\ x_i \tag{7}$$

That is, the observed cost is compared to the minimum cost which the firm would face, if using the optimal input

$$AE = EE / TE \tag{8}$$

Which measures firm i's relative ability to allocate the input-bundle in the cost-minimizing way, given the estimated technology. Also, this procedure includes any slacks into the allocative efficiency measure. This is often justified on the grounds that slack reflects an inappropriate input mix (Ferrier & Lovell, 1990).

All the models given above were solved for each individual sample farms. Paddy production (Y) in kg was used as output and men labour in man days, total women labour in women days, seeds in kg, plant nutrients (Nitrogen, Phosphorus, Potash) in kg and machine labour in hours were used as inputs (X). DEAP version 2.1 was used to solve all the above said input oriented DEA models.

3. Results and Discussion

3.1. Summary Statistics of Sample Farms

The summary statistics of paddy sample farms is presented in Table 1. It is observed that the significant difference exist among the farmers in the input usage and output realised. The paddy farm size ranged from 0.14 ha to 10 ha with the mean size of 2.11 ha. The yield of paddy realised by in sample farms ranged from 1616.01 kg/ ha to 6200.96 per/ha with the mean yield of 4456.40 kg/ha. The per ha mean usage inputs varied widely and in the case of seed it was 82.88 kg; similarly for labour it was 28.73 days of men labour and 135 days of women labour. Regarding fertiliser and machine power, the per hectare usage stood at 102.23 kg of nitrogen, 63.32 kg of phosphorus, 73.49 kg of potash and 16.13 machine hours.

Table 1. Summary statistics of sample farms

Inputs	Mean value	Minimum Value	Maximum Value
Farm Size in ha	2.11	0.14	10.0
Yield in Kg/ha	4456.40	1616.01	6200.96
Seed in Kg/ha	82.88	50.0	125.0
Men labour in days/ha	28.73	8.23	60.10
Women labour in days/ha	135.17	37.05	193.26
Nitrogen in kg/ha	102.23	48.16	227.24
Phosphorus in kg/ha	63.32	28.40	113.62
Potash in kg/ha	73.49	37.05	222.3
Machine labour in hours/ha	16.17	2.06	27.79

3.2 Overall Technical Efficiency, Pure Technical Efficiency and Scale Efficiency

The results of the DEA of paddy farms in Madurai district are given in Table 1. About 30 per cent of the sample farms were falling under the efficiency group (100 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 2.22 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 paddy production. Moreover, the overall technical efficiency of sample farms was ranging from 0.42 to 1.00 with mean efficiency score of 0.80. Similarly, the pure technical efficiency score was ranging from 0.44 to 1.00 with mean efficiency score of 0.85 and scale efficiency score was ranging from 0.62 to 1.00 with mean efficiency score of 0.95. Thus, the mean level of overall technical inefficiency was estimated as 20 per cent for paddy farms in the study region. 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 20 per cent through adoption of best practices of efficient farms. The decomposition of overall technical efficiency is given in Figure 1. As shown in the figure, pure technical inefficiency accounts for 15 per cent and scale inefficiency accounts for 5 per cent in overall technical efficiency of the paddy farms.

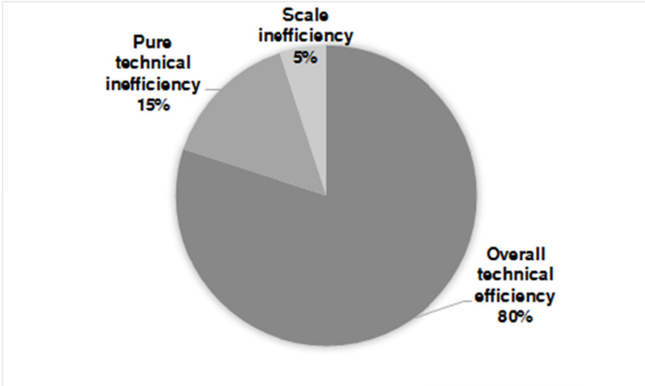

Figure 1. Percentage of pure and scale inefficiency in overall technical efficiency

Table 2. Frequency distribution and summary statistics on overall technical efficiency, pure technical efficiency, scale efficiency, allocative efficiency and economic efficiency measures in sample paddy farms

Efficiency level	Overall technical efficiency		Pure technical efficiency		Scale Efficiency		Allocative efficiency		Economic Efficiency	
	No. of farms	Per cent	No. of farms	Per cent	No. of farms	Per cent	No. of farms	Per cent	No. of farms	Per cent
Below 50	2	2.22	2	2.22	0	0.00	67	74.44	78	86.67
50-60	13	14.44	6	6.67	0	0.00	13	14.44	5	5.56
60-70	14	15.56	12	13.33	1	1.11	3	3.33	0	0.00
70-80	14	15.56	11	12.22	6	6.67	2	2.22	2	2.22
80-90	12	13.33	13	14.44	12	13.33	3	3.33	3	3.33
90-100	8	8.89	12	13.33	38	42.22	1	1.11	1	1.11
100	27	30.00	34	37.78	33	36.67	1	1.11	1	1.11
Total No. farmers	90	100.00	90	100.00	90	100	90	100.00	90	100.00
Minimum	0.42		0.44		0.62		0.22		0.18	
Maximum	1		1		1		1		1	
Mean	0.80		0.85		0.95		0.46		0.38	
Median	0.80		0.92		0.99		0.45		0.34	
Standard Deviation	0.17		0.16		0.08		0.15		0.17	

3.3 Allocative and Economic Efficiency

With respect to allocative efficiency, about 77.44 percent of sample farms were operating under below 0.50 level of allocative efficiency score. The implication of this result is that majority of the respondents are not allocatively efficient in the use of production resources. Furthermore, allocative efficiency among the respondents was ranging between 0.22 and 1.00, with a mean allocative efficiency score of 0.46. This result revealed that 54 percent of resources are inefficiently allocated relative to the best-practiced farms producing the same output and facing the same technology in the study area. This advocated that allocative efficiency among the respondents could be increased by 54 per cent in the study area through the better utilization of resources in optimal proportions for respective paddy production with the current state of technology. This would enable the farmers to equate the marginal revenue product (MRP) of input to the marginal input cost, thereby improving farm income.

As regards the economic efficiency, majority of the respondents (86.67 percent) operated within an efficiency score level of less than 0.50. This implied that majority of the respondents were not economically efficient in the use of production resources. This can result in higher costs per unit of output for a farm firm and hence the inability of the farmer to maximize profit. Moreover, economic efficiency score among the respondents varied widely ranging between 0.18 and 1.0, with a mean economic efficiency score of 0.38. This result suggested that the farmers in the study area were not able to minimize the cost of production. In other words, about 72 per cent of production costs were wasted relative to the best practiced farms producing the same output and facing the same technology in the study area. This exposed that overall economic efficiency among the respondents could be increased by 72 per cent through reduction in production costs that would occur if production were to occur at the allocatively and technically efficient point given the current state of technology. This would enable the farmers to minimize production costs, and hence maximize income and profit.

3.4 Scale of Operations in the Production Frontier

It 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, 28.89 per cent farmers are operating under sub-optimal situation, 34.44 per cent farmers are operating supra-optimal scale and 36.67 per cent of the farmers are operating at optimal scale condition. The results of the distribution of scale of operations in the production revealed that the about 29 per cent of the farmers had the scope to increase production by decreasing the input cost and about 34 per cent of famers could increasing their technical efficiency by reducing the production level.

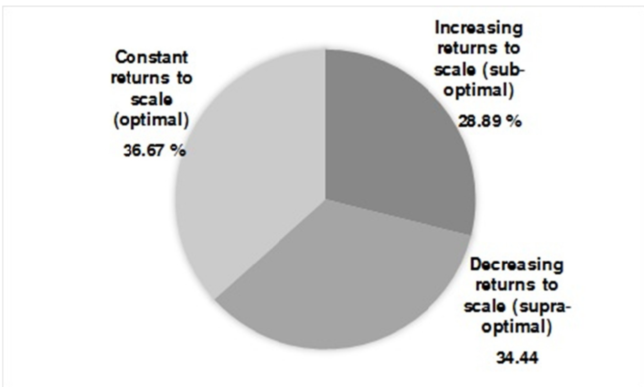

Figure 2. Distribution of scale of operation of paddy farms

3.5 Input Slacks and Number of Farms Using Excess Inputs

The mean input slacks and excess input use percentages are given in Table 2. 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. The greatest slacks were in women labour use followed by nitrogen fertilizers, seed materials, potassium fertilizers, men labour, machine labour and phosphorus fertilizers use. Out of the total number of farmers, about 51.11 per cent farmers were using excess women labour, followed by nitrogen fertilizers (50.00 per cent), men labour (28.89 per cent), potassium fertilizers (25.56 per cent), seed materials (24.44 per cent), machine labour (18.89 per cent) and phosphorus fertilizers (6.67 per cent).

Table 3. Input slacks and number of farms using excess inputs

Inputs	No. of Farms	% of farmers	Mean input Slack	Mean inputs used	Excess input use in per cent
Seed in Kg/ha	22	24.44	6.44	83.13	7.75
Men labour in days/ha	26	28.89	1.91	32.47	5.87
Women labour in days/ha	46	51.11	15.61	137.42	11.36
Nitrogen in kg/ha	45	50.00	13.45	113.47	11.85
Phosphorus in kg/ha	6	6.67	0.36	68.19	0.53
Potash in kg/ha	23	25.56	5.75	70.69	8.13
Machine labour in hours/ha	17	18.89	0.85	16.21	5.22

4. Conclusion

1) The results of the study showed that the technical efficiency score was 0.80. This indicated that there exist still a potential of 20 percent for increasing the paddy output of the farmers, if the production gap between the average and the best-practice farmers is narrowed.

2) The study showed that more than 60 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 respondents was attributed more to scale inefficiency than to the pure technical inefficiency.

3) In terms of allocative efficiency, still there is a potential of 54 percent for increasing output through optimal allocation of given inputs. With respect to economic efficiency, the results indicated that 87 percent of farmers are economically inefficient with a mean efficiency score of 0.38. This implied that there exist enormous potential for the farmers to increase output by adopting the best technology practices of optimal farms through optimal resource allocation.

4) Apart from these finding, it is curious to note that all the inputs were used excessively in the study region, particularly in the case of women labour by about fifty one percent of the farmers and in nitrogen by about fifty percent of the farmers.

5) The findings of the study emphasize the need to improve the overall technical and economic efficiency in the paddy growing farms of the region. Immediate steps on the part of government to ensure the provision of the necessary education, training, extension to bring in social change among farmers and other necessary support in the form of credit and other infrastructures in order to bring in technically and allocatively efficient paddy production in the study region.

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