International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2017; 5(5): 33-36

Received: 11-07-2017
Accepted: 12-08-2017

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Determination of technical efficiency in Paddy farms of canal irrigated systems in Tamil Nadu: A data envelopment analysis approach

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Abstract
This study is carried out to analyze the performance of paddy farms Cauvery delta zone in Tamil Nadu by estimating the level of technical efficiency. Data Envelopment Analysis (DEA), a nonparametric method was applied to estimate technical efficiency of paddy farms. The data collected for the year 2010-11 under the Cost of Cultivation Scheme of Tamil Nadu Centre were used for the study. The technical efficiency index ranged from 0.41 to 1.00 under both Constant Returns to Scale (CRS) and 0.48 to 1.00 under Variable Returns to Scale (VRS) specification. The mean technical efficiencies were 0.76 and 0.81 under CRS and VRS specification, respectively. The scale efficiency ranges between 0.75 and 1.00 with a mean of 0.93. Of the 100 Paddy farmers, nine shows constant returns to scale, 81 shows increasing return to scale while three shows decreasing return to scale. This result shows that there is small scale inefficiency in the study area. There are excess uses for all inputs especially for fertilizers like potash, phosphorus and farm yard manure.

Keywords: rice, canal irrigation, technical efficiency, scale efficiency, dea, crs, vrs

Introduction
Rice is the staple food of over half the world's population, (60 per cent) especially in East Asia, Southeast Asia, South Asia, the Middle East, and the West Indies. It is the predominant dietary energy source for 17 countries in Asia and the Pacific, nine countries in North and South America and eight countries in Africa. Rice provides 20 per cent of the world’s dietary energy supply. (FAO, 2004-05). According to the Food and Agriculture Organization, area and production of rice at the global level was 153.65 million hectare (MH) and 672 million tons (MT), respectively (FAO, 2010-11).

Technical efficiency can be output, reflecting the maximum output that can be achieved from each input, or alternatively representing the minimum input used to produce a given level of output. It describes the current state of technology in any particular industry (Hassan, 2004) [11]. The concept of technical efficiency including price efficiency and production efficiency was initially used by Farrell (1957) [9]. Hassan (2004) [11], Shah *et al.* (1994) [1] and Ali *et al.* (1994) [17] demonstrated an approach to determining the farm efficiency using DEA technique. It was further described by Seiford and Thrall (1990) [15] in terms of floating piece-wise linear surface to rest on top of the observations. Specifically, the key constructs of a DEA model are the envelopment surface and the efficient projection path to the envelopment surface (Charnes *et al.*, 1985) [4].The input-oriented model shows how much the input could be proportionally reduced without changing the quantity of the output produced while the output-oriented shows how much the output quantity could be proportionally expanded without altering the input quantity. Output-oriented model gives credence to neo-classical production function defined as the maximum output given input quantity (Fare *et al.*, 1994) [8]. In this study, the output-oriented model approach was used to estimate various efficiency indices.

The present study was undertaken in Cauvery delta zone in the state of Tamil Nadu to estimate the technical efficiency in rice production under canal irrigations. Usually the data envelopment analysis was used to estimate the performance efficiency of paddy farms in canal irrigated conditions.

Methodology
Sampling and Data Collection
The Cauvery delta zone is known as the *Rice Bowl of Tamil Nadu*. As such, the Cauvery delta zone was selected for canal irrigation purposively, for the present study. The data collected

under the cost of cultivation scheme were used. Under the scheme a stratified random sampling method was adopted. Thanjavur and Thiruvarur districts in the Cauvery delta Zone were covered for canal irrigation under the above scheme during the year 2010-11.
In Cauvery delta zone 109 farmers from seven taluks were selected for the present study.

Analytical framework
Data Envelopment Analysis
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 were two approaches, which were used commonly, to estimate the technical efficiency. According to Farrell (1957) [9], these approaches were classified into two basic groups: parametric and non-parametric frontier models. Stochastic frontier production function was a parametric method which needs specification of a functional and distribution forms for its joint error structure (Coelli and Battese, 1996) [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 were not possible in DEA model.

Model Specification
In present study, Data Envelopment Analysis model was used to estimate the technical and scale efficiency. Data Envelopment Analysis (DEA) is the methodology employed in order to estimate the relative efficiency of farms that operate under similar conditions and used the same number of inputs to produce identical outputs (Cooper *et al.*, 2000) [6]. Their difference lied solely on the quantities of inputs and outputs. It was a non-parametric approach and its mathematical formulation is as follows:
Objective function:

$$\text{Max} \quad \theta_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \tag{1}$$

Restrictions:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad (j = 1,2,\ldots\ldots n) \tag{2}$$

$$u_r \geq 0, \quad (r = 1,2,\ldots\ldots .s) \tag{3}$$

$$v_i \geq 0, \quad (i = 1,2,\ldots\ldots ..m) \tag{4}$$

where n = number of farms, j = farm whose relative efficiency is being measured, m= number of inputs, s=number of outputs, x_{ij}=quantity of input i in farm j, $y_{0=}$ quantity of output r from farm j, u_r = weight for output r, v_i= weight for input i, θ_j= relative efficiency of farm j.

With fractional programming, the researcher proceeds with the maximization of efficiency of farm j (1).Two restrictions were imposed in order to solve the problem: the weights cannot be negative (3 and 4) and relative efficiency was less than or equal to one ($\theta_j \leq 1$) (Ray, 2004) [14].
In turn, the fractional programming problem could be transformed into a linear programming problem (Charnes and Cooper, 1962) [3].
Objective function

$$\text{Max} \quad = \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \tag{5}$$

Restrictions :

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \; (j = 1,2,\ldots\ldots \ldots\ldots n) \tag{6}$$

$$\sum_{i=1}^{m} v_i x_{ij} = 1 \tag{7}$$

while (3) and (4) still hold.
The aim is to maximize function (5) or more to the point given restriction (7), to maximize the following:

Objective function

$$\text{Max} \quad \theta_j = \sum_{r=1}^{s} u_r y_{rj} \tag{8}$$

Under restrictions (3, 4) and

$$\sum_{r=1}^{s} u_r y_{rj} \leq 1 \tag{9}$$

The relative efficiency of farm j is θ_j and $\theta_j \leq 1$ is the imposed restriction. Farm j is efficient when:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} = 0 \rightarrow \sum_{r=1}^{s} u_r y_{rj}$$
$$= \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} = 1 \rightarrow \theta_j = 1$$

On contrary, when $\theta_j < 1$ farm j is inefficient.

The method relies in the use of linear programming to determine the production frontier for the sample of farms. All farms whose input-output ratio lies on the production frontier are technically efficient, while the degree of technical inefficiency of the others is measured by the Euclidean distance of the input-output ratio from the surface of the production frontier (Coelli *et al.*, 1998) [7].
This methodology was originally proposed some decades ago (Farell, 1957) [8]. Recently, DEA had been implemented in the agricultural sector to measure, amongst other things, efficiency in horticulture (Iraizoz *et al.*, 2003) [12], in the cotton sector (Shafiq and Rehman, 2000) [16] and in the sheep sector (Fousekis *et al*., 2001) [10].
The input oriented model was used and the measure of input efficiency indicated by how much input must be reduced by an inefficient farm, given the level of output, in order for it to become efficient. Overall Technical Efficiency (OTE) was measured by formula (8) and refers to Constant Returns to Scale (CRS) (Charnes and Cooper, 1978) [5]. OTE was distinguished into Pure Technical Efficiency (PTE) and Scale Efficiency (SE). PTE refers to Variable Returns to Scale (VRS) (Banker *et al.*, 1984) and can be measured if the

restriction If $\theta_{CRS} = \theta_{NIRS} < \theta_{VRS,}$ there were increasing returns to scale and if $\theta_{CRS} < \theta_{NIRS} = \theta_{VRS,}$ decreasing returns to scale. Relative efficiency measured on the basis of the Constant Returns to Scale if θ_{CRS} (OTE), θ_{NIRS} was for the Non-Increasing Returns to Scale and θ_{VRS} (PTE) for the Variable Returns to Scale model, respectively.

With DEA, efficiency was measured against feasible frontiers hence the improvement of each inefficient farm was also feasible through better management of available resources and external inputs. It should be mentioned through that the evaluation was done taking as a benchmark existing technology which was accessible at present to farm units and any currently available but not yet applied technology was not taken into account (Lansink and Reinhard, 2004) [13].

A second concern was related to making a choice between input and output oriented models. Although it was reported that in many cases this choice does not affect the results, an input oriented DEA model was chosen since farmers have more control on inputs than outputs. So that an input oriented DEA model was chosen.

One output and five inputs were used in the DEA model. The only output is the paddy yield per unit area (Qts/ha). The inputs included are (1) Seed applied to unit area (Kgs/ha), (2) Fertilizer (NPK Nutrient) applied to unit area (Kgs/ha), (3) Machine hours (Hrs/ha), (4) Human labour used (Hrs/ha)) and (5) Cost of Plant Protection chemicals (Rs/ha).

The software DEAP version 2.1 developed by Coelli (1996) [7] was used to estimate DEA scores. Farm's efficiency scores were calculated under constant and variable return to scale assumptions (CRS and VRS).

Results and Discussion

The summary statistics of variables for the production frontier estimation is presented in Table 1. Table 1 revealed that the yield of black pepper is 48.58 quintals/ha with a standard deviation of 9.83 quintals/ha. The small variability by the standard deviation implies that the farmer operated at the same levels of farm size which does not affect their yield levels. As it is seen from Table 1, small variations exist in all of the inputs. The variation is too low in the cost of Pesticide.

Table 1: Summary Statistics for variables used in the canal irrigated paddy farms

Input/output variables	Minimum	Maximum	Mean	SD
Yield(Quintals/Ha)	32.11	77.34	48.58	9.83
Inputs used in paddy cultivation				
Seed (Kgs/ha)	38.46	142.86	91.36	16.55
N,P,K nutrients (Kgs/ha)	119.39	354.50	210.12	36.08
Labour (hrs/ha)	121.21	2625.53	976.32	598.33
Machine (hrs/ha)	255.93	4686.91	573.60	431.37
Pesticide (Rs)	2.66	15.00	6.02	2.33

DEA results

The data estimated by using Data Envelopment analysis (Computer) Program (Coelli, 1996) [7]. The technical efficiency scores among farms are presents in Table 2. Mean of technical efficiency under technical efficiency under constant returns to scale (TEcrs) assumption and under technical efficiency under variable returns to scale (TEvrs) assumption is 0.76 and 0.93, respectively.

On average, the farmers are only producing 76 per cent (CRS) and 93 per cent (VRS) of the output of best-practices farmers at the same level inputs. This means, farms should improve about 7 per cent (VRS) and 24 per cent (CRS) of the efficiency in input utilization at the same production level.

Technical efficiency scores under CRS (TEcrs) and under VRS (TEvrs) range from 0.52 to 1.00 and 0.67 to 1.00, respectively. Under TEcrs 11 farms are technically efficient while under TEvrs 31 farms are technically efficient. This means that the number of farms achieving full technical efficiency under TEvrs assumption is more than the number of farms achieving full technical efficiency under TEcrs assumption. Technical efficiency under VRS-DEA model was higher than CRS-DEA model implying that the VRS-DEA model more flexible and envelops the data in a tighter way than the CRS-DEA model. Meanwhile, scale efficiency (SE) scores of farms range from 0.60 to 1.00 where 12 farms are scale efficient and a mean value of scale efficiency is 0.82. The mean of scale efficiency of farms is relatively high (0.82), indicating that farm inefficiencies are due to inefficiency in input use.

Table 2: Frequency distributions of technical efficiency scores obtained with DEA model

Efficiency scores	CRS	VRS	SE
below 0.8	70	6	56
0.81-.84	6	9	14
0.85 - 0.89	7	19	8
0.90-0.94	7	19	7
0.95-0.99	8	25	12
1	11	31	12
Total Farmers	109	109	109
Mean	0.76	0.93	0.82
Minimum	0.52	0.67	0.60
Maximum	1.00	1.00	1.00
Standard Deviation	0.15	0.07	0.12

Input slack and excess input use

The mean input slacks and excess input use percentages are given in Table 4. Since a slack indicates excess of an input, a farm can reduce its expenditure on an 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 Potash fertilizer followed by farm yard manure, Phosphorus fertilizer, Nitrogen fertilizer, cost for plant protection chemicals and Human labour.

According to these results, sample farms could reduce potash fertilizer use by 20 per cent staying at the same production level. Number of farms using excess nitrogen fertilizer is also high (74). This analysis reports excess use for all inputs especially for fertilizers like potash, phosphorus and farm yard manure. Moreover, inputs such as nitrogen, potash, and phosphorus and manure usage were used excessively by more than 50 per cent of the farmers and cost of plant protection chemicals and human labour were used excessively by only less than 50 per cent of the total farmers. The value of manure slack was observed to be 0.89 ha. This indicates that usage of farm yard manure could be reduced by this amount to obtain the same level of output. The nitrogen fertilizer slack of 8.34kg implies that there should be reduction in the use of nitrogen fertilizer by 8.34kg. In essence, the same level of output that were realized from this inputs use could still be obtained if the quantity of the various inputs were reduced by the corresponding values of slacks among the inputs.

Table 3: Input slack and number of farms using excess inputs

Inputs	No. of Farms	Mean Slack	Mean Input use	Excess Input use (%)
Seed (Kgs/ha)	5	0.33	91.36	0.36
N,P,K nutrients (Kgs/ha)	17	4.46	210.12	2.12
Labour (hrs/ha)	45	224.54	976.32	23.00
Machine (hrs/ha)	18	51.28	573.60	8.94
Pesticide (Rs)	11	0.09	6.02	1.50

Conclusion

This study set out to provide technical efficiency (TE) of paddy production in canal irrigated region and to explain variations in technical efficiency among farms. Farm specific technical efficiencies of paddy farms were computed using production data (2010-11). An input oriented DEA approach was used to generate technical efficiency. Results show that, mean technical efficiency is estimated at 76 per cent. Therefore, there is a 24 per cent scope for increasing paddy production by using the present technology. However, TE ranges between 52 to 100 per cent among the paddy growers in canal irrigated region. The findings in this study show that paddy farms are technically inefficient where the mean technical efficiency of paddy farms is low. Farms are not efficient in input utilization and are not producing paddy yield at maximum level hence they are not minimizing cost and maximizing profit. The greatest excesses were observed in labour usage and machine hours. All these excesses adversely affect technical efficiencies of paddy pepper farming. Inefficiencies indicate a wrong mixture of these inputs. The inefficiencies are due to improper farm management and misallocation of inputs used. Thus, growers in the region must be educated about the use of fertilizers through agronomic education by extension agents in order to improve their effectiveness.

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