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EFFCIENCY ANALYSIS: AN INSIGHT INTO DEA COST MODEL AND ITS APPLICATION

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ABSTRACT

This paper presents a mathematical programming approach, known as Data Envelopment Analysis(DEA) to provide a relative cost efficiency estimate of 180 maize farmers. DEA with multiple number of inputs and outputs is a non-parametric efficiency evaluation method and it is widely applied by researchers in efficiency evaluations of various sectors. Farming is not only about the production hence emphasis is given on input oriented cost minimization technique. Six inputs and one output were considered for this study. Cost efficiency of decision making units(DMU) by DEA is carried out through linear programming methods and it compares the efficiencies among different units. DMUs that lie on the frontier curve are efficient in selecting the optimum input and producing the desired amount of output at minimum cost. The result shows that only 40% of the samples were on the frontier line.

KEYWORDS: Mathematical programming, Non-parametric, Data envelopment analysis, Decision making units, linear programming, cost efficiency.

I. INTRODUCTION

Several Parametric and nonparametric approaches at different levels has been used in the measurement of technical, allocative and economic efficiencies. Parametric frontier depends upon specific functional form and can be either deterministic or stochastic, Thiam et al [15]. The main advantage of DEA is that it doesn't require any prior assumptions on the functional form or relationship between inputs and outputs, Seiford and Thrall [13]. Interest in measuring efficiency is gained when the sources of inefficiencies can be analysed and quantified for every evaluated unit and DEA is used for this purpose. In addition, DEA is a data-driven frontier analysis technique that floats a piecewise linear surface to rest on top of the empirical observations, Pahlvan.R.et al [11]. DEA a mathematical programming developed by Charnes et al [1] is based on linear programming to estimate the efficiency of DMUs has its roots from Farrell M.J [6] who described Economic efficiency in terms of Technical and Allocative efficiencies. In the input minimisation case, a DMU is not efficient if it is possible to decrease any input without augmenting any other input and without decreasing any output, Charnes et al [2]. In DEA, the efficiency of these decision making units is assessed by solving a pair of mutually dual linear programming problems; one of them is envelopment model and the other as the multiplier model, Podinovski V.V. [12]. Various theoretical and methodological improvements have been carried out since then. These developments have been applied to very broad range of areas like Fuzzy Weights in Data Envelopment Analysis by Khalid Shafooth Khalaf et al [4], For The Relative Efficiencies of Research Universities of Science and Technology in China proposed by Wang Chuanyi and Lv Xiaohong [16], cost minimization in Fuzzy DEA model suggested by Shinto and Sushama [14] are few of them. Mirdehghan [10] proposed a model for evaluating the measure of efficiency when some input prices and some output benefits are available for all DMUs. In agricultural sectors DEA studies deals with the efficiency in different perspective and in its evaluation, they focus on various subjects. Ehsanollah Mansourirad et al [5] in their study investigated farmers' technical efficiency through DEA models considering water use as one of the inputs. Liu ke-fei [9] used DEA, to quantitatively measure the efficiency of the

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development of agricultural circular economy in Zhengzhou province, based on the result to obtain the adjustment in the invalid region. Maize is a cereal crop which is cultivated widely throughout the world and has the highest production among all the cereals. In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries etc.

This paper uses recent survey data (2015-2016) from two blocks of Coimbatore state in India for the estimation of cost efficiency of the farmers using DEA. The main objective of the study is to identify the inefficient units and the magnitude of inefficiency as well as to determine the input techniques used by more efficient units that should be introduced into less efficient units.

II. MATERIALS AND METHODS

DEA Model

DEA models are designed under different Returns to Scale (RTS) assumptions. This paper uses the original model CCR . To calculate efficiencies a set of linear programming should be solved. As DEA is based on Technical efficiency, which is maximizing outputs from given inputs.

Hence, $$TE = \max z_0 = \frac{\sum_{i=1}^{m} u_i y_{ik}}{\sum_{j=1}^{n} v_j x_{jk}} \quad \text{s.t} \quad \frac{\sum_{i=1}^{m} u_i y_i}{\sum_{j=1}^{n} v_j x_j} \le 1,\ k = 1,2,3\ldots\ldots s,\quad u_i, v_j \ge 0 \tag{1}$$

Dual of above is given by,

$$\min f_0 = \frac{\sum_{j=1}^{n} v_j x_j}{\sum_{i=1}^{m} u_i y_i},\ \text{s.t} \quad \frac{\sum_{j=1}^{n} v_j x_j}{\sum_{i=1}^{m} u_i y_i} \ge 1,\quad k=1,2,3\ldots\ldots s,\ u_i, v_j \ge 0 \tag{2}$$

Here y_i , x_j are the output and input , $u_i, v_j \ge 0$ are the weights for corresponding output and input.

Converting the nonlinear (fractional) mathematical programming to linear we get, $\max g_0$ s.t

$$-\sum_{k=1}^{s} y_{ik}\lambda_k + y_{i0}h_0 \le 0\ ,\ i = 1,2,\ldots\ldots m$$

$$\sum_{k=1}^{s} x_{jk}\lambda_k \le x_{j0},\ j = 1,2,\ldots\ldots n\ ,\ \lambda_k \ge 0\,,\ k = 1,2,\ldots\ldots s \tag{3}$$

Hence corresponding production possibility set under CRS for the input vector x_j and output vector y_i is given by, $$P(y) = \left\{ (x, y) : x_j \ge \sum_{k=1}^{s} \lambda_k x_{jk}; y \le \sum_{k=1}^{s} \lambda_k y_{ik}; \lambda_k \ge 0, j = 1,2,\ldots.n, i = 1,2,\ldots.m \right\} \tag{4}$$

Dual of ordinary linear programming in (3) is,

$$\min h_0 = \sum_{j=1}^{n} w_j x_{j0}\ ,\ \text{s.t} \quad -\sum_{i=1}^{m} \upsilon_i y_{ik} + \sum_{j=1}^{n} w_j x_{jk} \ge 0$$

$$\sum_{i=1}^{m} \upsilon_i y_{i0} = 1\ ,\ \upsilon_i, w_j \ge 0 \tag{5}$$

h_0 is the radial measure of technical efficiency.

Definition 1: If the optimal values in (4) equals one then DMUs are technically efficient.

Coeill et al [3] suggested input oriented DEA model as,

$$\min \theta \text{ s.t } \theta x_0 \geq \sum \lambda_i x_j \ , \ y_0 \leq \sum \lambda_i y_i \ , \ \lambda \geq 0$$

Where $\lambda =$ weight assign to DMU, $\theta =$ Efficiency of DMU, $x_j, y_i =$ Input and output vectors, x_0, y_0 = input and output into DMU

Since we focus only on one output, which is same for every DMUs and dropping out extra subscripts on the $y_k, k = 1,2,3......s$ .Scale change in variable yields $\lambda_k = \frac{\lambda_k^{'}}{y_k}$ *and* $g_0 = \frac{g_0^{'}}{y_0}$. (3) after dropping the primes and $\frac{1}{y_0}$ yileds,

$$\max g_0 = \sum_{k=1}^{s} \lambda_k \text{ s.t } \sum_{k=1}^{s} x_{jk}^{'} \lambda_k \leq x_{j0}^{'} \ , \ j = 1,2,......n \qquad (6)$$

$$\lambda_k \geq 0 \ , \ k = 1,2,......s \text{ where } x_{jk}^{'} = \frac{x_{jk}}{y_k}, k = 1,2,.......s \text{ and } x_{j0}^{'} = \frac{x_{j0}}{y_0}$$

(5) can be re written as, $\max g_0 = \sum_{k=1}^{s} \lambda_k$ s.t $\sum_{k=1}^{s} p_k \lambda_k \leq p_0$, $\lambda_k \geq 0$, $k = 1,2,......s$

Farrell [6] distinguished efficiency in terms of Technical, Allocative and Economic efficiencies.

Definition 2: Cost efficiency is the product of Technical and Allocative efficiencies.

$(Ce_i = Te_i \times Ae_i)$.

$$Te_i = \min\{\theta : \theta x \in L(y)\} \, ; Ce_i = \min\{w^T x : x \in L(y)\}$$

$\therefore Ae_i = \frac{Ce_i}{Te_i} = \frac{\min\{w^T x : x \in P(y)\}}{\min\{\theta : \theta x \in P(y)\}}$, where P(y) is the set of production technology.

Cost function should focus on how firms decide on the combination of inputs in order to minimise the cost. While going for cost minimisation two cases need to be considered.

Case i) If a firm is technically efficient ($Te_i = 1$) and but doesn't exhibit allocative efficiency ($Ae_i < 1$) then the firm is not cost efficient ($Ce_i < 1$).

Case ii) If $Ae_i = 1$ and $Te_i < 1$, the firm is again cost inefficient ($Ce_i < 1$).

If the production unit fails to demonstrate any of these three types of efficiency ($Te_i < 1$; $Ae_i < 1$; $Ce_i < 1$), then the value of overall cost efficiency can be interpreted as a potential costs saving that can be achieved if the production unit uses the inputs in optimal combination. Potential costs saving can be calculated by subtracting the value of overall cost efficiency from the number one, Kristína Kočišová [8].

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A cost frontier is function $c(y,w)=\min\{w^{'},x\}$ such that $T(y,x)=0$,where $w=(w_1,\ldots\ldots..,w_s)$ is the positive vector of input prices.

Dual of (5) is given by, $\min\ h_0=q^{'}p_0$, s.t $q^{'}p_k\geq 1$, $w^{'}\geq 0\quad k=1,2,\ldots\ldots s$

$q^{'}$ is the transpose of the column vector w, $q^{*'}$ is normal to the hyperplane containing facets. Equation to the hyperplane is $q^{*'}x=1$,Charnes et al[1]. Let M be the matrix $(m_{s1},m_{s2},\ldots\ldots.m_{sk})^T$, which represent the set of coefficients with n^th efficient facet from the estimated data and w be a matrix with its column vector w_k $k=1,2,\ldots\ldots s$.

Hence,

$$\min(w_1\quad w_2\quad .\quad .\quad w_s)^{'}(x_1\quad x_2\quad .\quad .\quad x_j)\ \text{s.t}$$

$$(m_{n1}\quad m_{n2}\quad .\quad .\quad .\quad .\quad m_{nk})^T(x_1\quad x_2\quad .\quad .\quad x_j)\geq(y_1\quad y_2\quad .\quad .\quad y_m)(1\quad .\quad .\quad .\quad 1_k)^T\ ;$$

$$-(w_1\quad w_2\quad .\quad .\quad w_s)(\lambda_1\quad \lambda_2\quad .\quad .\quad \lambda_s)+\begin{pmatrix}1 & . & . & 0\\ 0 & 1 & . & 0\\ . & . & . & .\\ . & . & . & .\\ 0 & 0 & 0 & 1_s\end{pmatrix}(x_1\quad x_2\quad .\quad .\quad x_s)=0\ ;$$

$$(\lambda_1\quad \lambda_2\quad .\quad .\quad \lambda_s)\geq 0 \qquad (7)$$

Dual of (6) is given by, $\max\ y\mu^{'}e$ s.t $\mu^{'}M+u^{'}I=w^{'};-u^{'}w\leq 0;\ \mu^{'}\geq 0$

where e is the column vector with all elements 1. I , the identity matrix.

Using duality theorem we get $w^{'}x\geq y\mu^{'}e$ for all x,μ,u,λ which satisfy the constraints.

And $w^{'}x^{*}=y\mu^{*'}e$, where x^{*} is the input quantities which are decision variables.

Hence , $c(y,w)=y\mu^{*'}e=w^{'}x^{*}$ (8)

Above is the required cost minimising function , here $c(y,w)$ varies with every y and w.

Definition 3: If the optimal values in (8) equals one then DMUs are cost efficient

III. RESULTS AND DISCUSSION

Selection of inputs and outputs

This section describes practical application of DEA under constant return to scale (CRS) using DEAP software. In this paper we have applied cost data collected through multistage stratified sampling technique on maize cultivation for the year 2015-2016.180 maize farmers were considered for the study. Seeds x_1, Labour x_2, Machinery x_3, Fertilizer x_4, Plant protection chemicals x_5 and irrigation x_6 are the independent and yield is the dependent variable. Corresponding input prices are denoted as w_1, w_2, w_3, w_4, w_5, w_6.

Empirical analysis and Results

Table 1 shows descriptive statistics on inputs in terms of quantities, cost and yield obtained. W_2 calculations are based on the total amount spend on total number of labours. w_3 and w_6 are estimated on total cost to the number of hours and number of irrigations (in total) respectively. DMUs which lie on the frontier curve represents virtual performance, not optimal one in its theoretical concept. Accordingly, they reflect the actual style of the distribution process of resources and products Frija et al [7].

Table 1 Summary Statistics on variables used for cost efficiency estimation

	Minimum	Maximum	Mean	Standard deviation
Yield /quintal/ha	12	75	40.6	13.7
x_1 / kg	10	26	17.4	4.5
x_2 /No.of labours	15	60	36.4	8.6
x_3 / hours	1	6	1.47	0.75
x_4 /kg	20.2	63.7	46.9	10.5
x_5 /kg	0.75	2.25	1.5	0.3
x_6 /No.of irrigations	3	10	6.8	2.15
w_1	263	5280	1667	1057
w_2	2300	13300	7394	1801
w_3	0	3850	1514	614
w_4	332	1500	904	235
w_5	25	640	380	72.6
w_6	0	3000	726	461

Table 2 shows DEA results with CRS for 180 maize farmers. Among the 180 farmers Sample Number 50 has achieved cost efficiency level ($Ce = 1$) as he /she is technically and allocative efficient ($Te = 1$; $Ae = 1$). Rest of the farmers are technically efficient but not allocative ($Te = 1$; $Ae < 1$) or vice versa. Mean technical efficiency score is 0.63, which shows 37% of farmers are technically inefficient. 0.64 is the estimated mean allocative efficiency indicating 36% of farmers uses minimum inputs but the proportion of inputs doesn't promise the minimum possible cost. The optimal input combination used by sample number 50 can be adopted for achieving cost efficiency. Figure shows the comparison between technical, allocative and cost efficiencies. It shows that farmers who are technically efficient are not allocative or cost efficient.

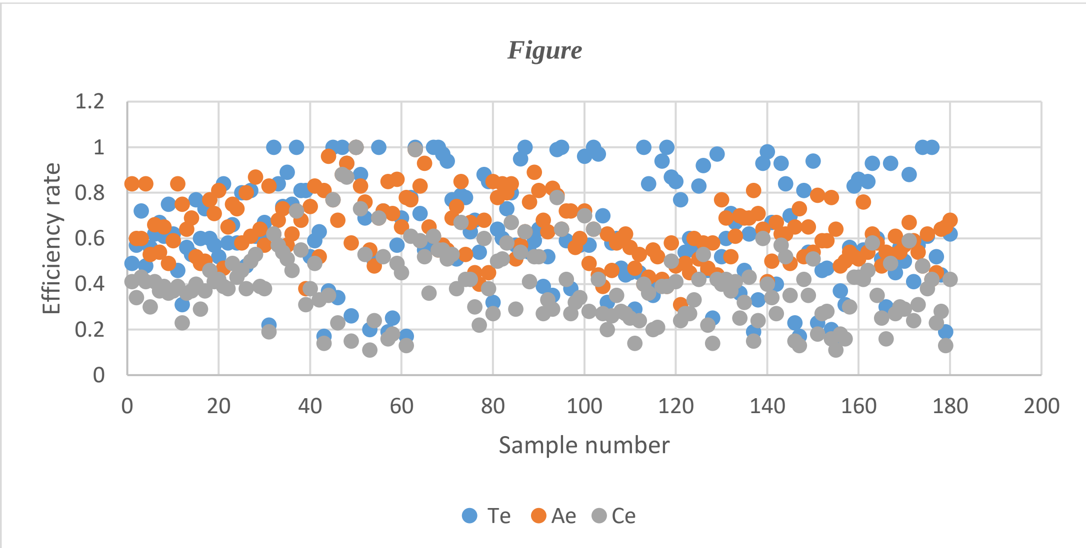

Table 2 DEA estimate with CRS

Sample No.	Te	Ae	Ce	Sample No.	Te	Ae	Ce	Sample No.	Te	Ae	Ce	Sample No.	Te	Ae	Ce
f1	0.49	0.84	0.41	f46	0.34	0.68	0.23	f91	0.39	0.68	0.27	f136	0.62	0.69	0.43
f2	0.57	0.6	0.34	f47	1.00	0.88	0.88	f92	0.52	0.63	0.33	f137	0.19	0.81	0.15
f3	0.72	0.6	0.43	f48	0.93	0.93	0.87	f93	0.35	0.82	0.29	f138	0.33	0.71	0.24
f4	0.48	0.84	0.41	f49	0.26	0.58	0.15	f94	0.99	0.79	0.78	f139	0.93	0.64	0.6
f5	0.56	0.53	0.3	f50	1.00	1.00	1.00	f95	1.00	0.64	0.64	f140	0.98	0.41	0.4
f6	0.62	0.66	0.41	f51	0.88	0.83	0.73	f96	0.59	0.72	0.42	f141	0.67	0.5	0.34
f7	0.67	0.54	0.37	f52	0.69	0.76	0.53	f97	0.38	0.72	0.27	f142	0.4	0.67	0.27
f8	0.61	0.65	0.39	f53	0.2	0.55	0.11	f98	0.57	0.56	0.32	f143	0.93	0.62	0.57
f9	0.75	0.49	0.36	f54	0.5	0.48	0.24	f99	0.57	0.6	0.34	f144	0.84	0.62	0.52
f10	0.62	0.59	0.37	f55	1.00	0.69	0.69	f100	0.96	0.72	0.7	f145	0.7	0.49	0.35
f11	0.46	0.84	0.39	f56	0.72	0.72	0.52	f101	0.57	0.49	0.28	f146	0.23	0.65	0.15
f12	0.31	0.75	0.23	f57	0.19	0.85	0.16	f102	1.00	0.64	0.64	f147	0.17	0.73	0.13
f13	0.56	0.64	0.36	f58	0.25	0.71	0.18	f103	0.97	0.44	0.42	f148	0.81	0.52	0.42
f14	0.53	0.69	0.37	f59	0.57	0.86	0.49	f104	0.7	0.39	0.27	f149	0.54	0.65	0.35
f15	0.77	0.52	0.4	f60	0.69	0.65	0.45	f105	0.32	0.62	0.2	f150	0.94	0.54	0.51
f16	0.6	0.49	0.29	f61	0.17	0.78	0.13	f106	0.58	0.46	0.26	f151	0.23	0.79	0.18
f17	0.73	0.5	0.37	f62	0.78	0.77	0.61	f107	0.6	0.58	0.35	f152	0.46	0.59	0.27
f18	0.6	0.77	0.46	f63	1.00	0.99	0.99	f108	0.47	0.6	0.28	f153	0.47	0.59	0.28
f19	0.57	0.71	0.41	f64	0.71	0.83	0.59	f109	0.44	0.62	0.27	f154	0.2	0.78	0.16
f20	0.52	0.81	0.42	f65	0.55	0.93	0.52	f110	0.45	0.56	0.25	f155	0.17	0.64	0.11
f21	0.84	0.47	0.39	f66	0.56	0.65	0.36	f111	0.29	0.47	0.14	f156	0.37	0.48	0.18
f22	0.58	0.65	0.38	f67	1.00	0.61	0.61	f112	0.45	0.53	0.24	f157	0.31	0.5	0.16
f23	0.66	0.75	0.49	f68	1.00	0.55	0.55	f113	1.00	0.4	0.4	f158	0.56	0.54	0.3
f24	0.58	0.73	0.43	f69	0.97	0.57	0.55	f114	0.84	0.43	0.36	f159	0.83	0.52	0.43
f25	0.8	0.58	0.46	f70	0.94	0.55	0.51	f115	0.35	0.55	0.2	f160	0.86	0.51	0.43
f26	0.48	0.8	0.38	f71	0.77	0.69	0.53	f116	0.4	0.52	0.21	f161	0.55	0.76	0.42
f27	0.81	0.61	0.5	f72	0.51	0.74	0.38	f117	0.94	0.42	0.39	f162	0.85	0.54	0.46
f28	0.61	0.87	0.53	f73	0.79	0.85	0.67	f118	1.00	0.39	0.39	f163	0.93	0.62	0.58
f29	0.61	0.64	0.39	f74	0.78	0.53	0.42	f119	0.87	0.58	0.5	f164	0.6	0.58	0.35
f30	0.67	0.57	0.38	f75	0.63	0.67	0.42	f120	0.85	0.48	0.41	f165	0.51	0.48	0.25
f31	0.22	0.83	0.19	f76	0.68	0.45	0.3	f121	0.77	0.31	0.24	f166	0.3	0.54	0.16
f32	1.00	0.62	0.62	f77	0.54	0.4	0.22	f122	0.54	0.49	0.27	f167	0.93	0.53	0.49
f33	0.84	0.68	0.57	f78	0.88	0.68	0.6	f123	0.6	0.45	0.27	f168	0.45	0.61	0.27
f34	0.74	0.73	0.54	f79	0.85	0.45	0.38	f124	0.55	0.6	0.33	f169	0.56	0.54	0.3
f35	0.89	0.57	0.51	f80	0.32	0.85	0.27	f125	0.83	0.51	0.42	f170	0.5	0.57	0.29
f36	0.75	0.62	0.46	f81	0.64	0.78	0.5	f126	0.92	0.58	0.53	f171	0.88	0.67	0.59
f37	1.00	0.72	0.72	f82	0.6	0.84	0.51	f127	0.46	0.47	0.22	f172	0.41	0.59	0.24
f38	0.81	0.68	0.55	f83	0.73	0.8	0.58	f128	0.25	0.58	0.14	f173	0.57	0.54	0.31
f39	0.81	0.38	0.31	f84	0.8	0.84	0.67	f129	0.97	0.44	0.42	f174	1.00	0.48	0.48
f40	0.52	0.74	0.38	f85	0.57	0.51	0.29	f130	0.52	0.77	0.4	f175	0.61	0.62	0.38
f41	0.59	0.83	0.49	f86	0.95	0.57	0.54	f131	0.6	0.69	0.42	f176	1.00	0.42	0.42
f42	0.63	0.52	0.33	f87	1.00	0.63	0.63	f132	0.71	0.52	0.37	f177	0.52	0.45	0.23
f43	0.17	0.81	0.14	f88	0.54	0.76	0.41	f133	0.67	0.61	0.41	f178	0.44	0.64	0.28
f44	0.37	0.96	0.35	f89	0.59	0.89	0.52	f134	0.36	0.7	0.25	f179	0.19	0.65	0.13
f45	1.00	0.77	0.77	f90	0.64	0.81	0.52	f135	0.46	0.69	0.32	f180	0.62	0.68	0.42

f = Farmer, Te = Technical efficiency, Ae= Allocative efficiency, Ce= Cost efficiency.

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IV. CONCLUSION

This paper is focused on mathematical linear programming nonparametric approach DEA with CRS for the measurement of cost efficiency among maize farmers. Agriculture production is the primary economic sector in many parts of the world. The gap between the demand and supply of food has been increasing due to the land reform, low agricultural productivity and production inefficiencies. Key improvement in improving the production efficiency is focusing on efficient usage of scarce economic resources. Cost efficiency is considered most important as the firms can achieve it, if the combination of correct inputs are used. Results shows that most of the farmers are technically efficient but not allocative ($Te = 1\,;\, Ae < 1$) or vice versa hence there is a need to focus on improving the selection of optimal inputs. DEA helps in calculating cost minimizing technique so that firm can improve their efficiencies.

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