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ASSESSING INFEASIBILITY IN SUPER-EFFICIENCY DEA MODELS

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Abstract. Performance or efficiency evaluation is an important aspect in production process. Both parametric and non-parametric methods are available for performance/efficiency evaluation. Data envelopment analysis (DEA) is one of the most popular non-parametric techniques based on linear programming approach used for measuring efficiency of similar type of organizations, generally termed as Decision Making Units (DMUs), with multiple inputs and outputs. DEA provides efficiency scores for each DMU and benchmarks (peers) inefficient units. Then the Decision Making Units could be ranked based on peer counts. But tie may occur among the ranks. So to break the tie, the super-efficiency model by Andersen and Peterson [1], is applied in this study. Super-efficiency model yields infeasibility and the same is verified with the necessary conditions for identifying infeasibility proposed by Seiford and Zhu [12]. In this paper, we have considered manufacturing industries pertaining to dairy products in India with 3 inputs and 2 outputs and the results based on the empirical investigation are outlined.

1. Introduction

India has been the leading producer and consumer of dairy products with a sustained growth in the availability of milk and milk products. Dairy products form an essential part of the rural Indian economy, serving as an important source of employment and income. On account of this, the Indian dairy industry holds tremendous potential for value addition and overall development.

Based on the above facts, the author in this study attempted to measure the relative efficiency of manufacturing units of dairy products in India. There are many methods, including parametric and nonparametric, available for efficiency measurement, out of which Data Envelopment Analysis is a powerful tool used for measuring efficiency of similar type of units generally known as Decision Making Units (DMUs).

Data Envelopment Analysis is a non-parametric technique based on linear programming problem used for measuring the relative efficiency of a homogenous set of decision making units in the presence of multiple inputs and multiple outputs. Similar type of organizations such as Banks, Hospitals, Schools, Industries etc., which consumes identical inputs and produce identical outputs are few examples of Decision Making Units.

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Farell [7] pioneering work on the measurement of productive efficiency of firms has inspired several studies on efficiency measure based on the production frontier. Charnes et al [5] proposed the basic DEA model to evaluate the relative efficiency of the decision making units using Constant Return to Scale (CRS) assumption. Banker et al [2] provides models for estimating technical and scale efficiencies of decision making units with reference to efficient production frontier. The sensitivity of the efficiency classifications was studied by Charnes et al [4] using super-efficiency model. The superefficiency model for ranking the efficient DMUs was proposed by Andersen and Petersen [1]. Seiford and Zhu [12] provides the necessary and sufficient condition for the super-efficiency DEA measures. Lovell and Rouse [10] have included sensitivity analysis, outlier identification and inter-temporal analysis in DEA. Chen [6] measures super-efficiency in DEA in the presence of infeasibility. Khodabakhshi et al [8] developed an input-oriented super-efficiency measure in stochastic data envelopment analysis. Lee and Zhu [9] proposed a new super-efficiency DEA model which is always feasible when data are non-negative. Yang et al [15] studied the environmental efficiency of China based on environmental super-efficiency data envelopment analysis model by using data of 30 provinces in China during the period of 2000–2010. Thilagam and Prakash [13] applied analytical methods for studying the sensitivity of DEA results to variations in the data. Wang [14] assessed and compared two popular methods, data envelopment analysis and heuristic rank aggregation approach in the context of ranking of multiple input and multiple output units. Bolouri et al [3] proposed a model for ranking extreme efficient DMUs in DEA by super-efficiency technique and Euclidean norm. Sojoodi et al [11] studied the efficiency of various types of thermal power plants in Iran using three super-efficiency models.

The paper is organized as follows. In Section 2, the methodology has been presented. The Section 3 deals with the Empirical Investigations and the conclusion is discussed in Section 4.

2. Methodology

Assume that there are n units each consuming m inputs to produce s outputs. Let y_{rj} denote the level of the r^{th} output $(r = 1, 2, \ldots, s)$ from unit j $(j = 1, 2, \ldots, n)$ and x_{ij} denotes the level of the i^{th} input $(i = 1, 2, \ldots, m)$ to the j^{th} unit. Charnes et al [5] initially developed the following output maximization model with the formation of virtual input (weighted sum of inputs) and virtual output (weighted sum of outputs)

$$
\begin{aligned}
& Max\ z = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \\
& Subject\ to \\
& \qquad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1;\ j = 1, 2, \ldots, n \qquad (2.1) \\
& u_r, v_i \geq 0;\ r = 1, 2, \ldots, s;\ i = 1, 2, \ldots, m
\end{aligned}
$$

where u_r is the weight of r^{th} output and v_i is the weight of i^{th} input
When the above model runs for each DMU it gives the efficiency score and the

weights u_r and v_i which leads to efficiency. Charnes et al [5] brought modifications on the non-negativity constraints $u_r, v_i \geq 0$ through ϵ and changed it as $u_r, v_i \geq \epsilon$ where $\epsilon > 0$ is a non-Archimedean infinitesimal constant.

The above is a fractional linear programming problem and it is difficult to solve. So a transformation proposed by Charnes et al. [5] for fractional programming, converted the above fractional program into linear programming problem.

$$\begin{aligned}
&Max\ z = \sum_{r=1}^{s} u_r y_{rj} \\
&Subject\ to \\
&\sum_{i=1}^{m} v_i x_{ij} = 1 \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij}\ j = 1, 2, \ldots, n \\
&u_r, v_i \geq \epsilon;\ r = 1, 2, \ldots, s;\ i = 1, 2, \ldots, m
\end{aligned} \tag{2.2}$$

When the above problem is solved for n times, once for each unit in the sample, it gives the optimal solution (z^*, u^*, v^*). The evaluated DMU is said to be CCR efficient if $z^* = 1$ and there exists at least one optimal (u^*, v^*) with $u^*, v^* > 0$. Otherwise the evaluated DMU is CCR inefficient. This problem is known as a primal problem.

The concept of LPP states that every primal has its own dual. Thus the dual of CCR DEA known as input oriented DEA model is given below

$$\begin{aligned}
&Min\ \theta_0 \\
&Subject\ to \\
&\sum_{j=1}^{n} y_{rj} \lambda_j \geq y_{r0};\ r = 1, 2, \ldots, s \\
&\sum_{j=1}^{n} x_{ij} \lambda_j \leq \theta_0 x_{i0};\ i = 1, 2, \ldots, m \\
&\lambda_j \geq 0;\ j = 1, 2, \ldots, n \\
&\theta_0\ unrestricted(free)
\end{aligned} \tag{2.3}$$

where θ_0 is a scalar and λ_j is the weight of the j^{th} DMU
By solving the above model it gives the efficient score θ^* and DMU weights λ. The evaluated DMU is efficient iff $\theta^* = 1$, $\lambda_j = 1$ for $\lambda_j = \lambda_O$ and $\lambda_j = 0$ for all other DMUs. Otherwise the evaluated DMU is inefficient.

The above CCR model is based on constant returns to scale assumption. So next to CCR, Banker et al. [2] introduced another model with convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$, which admits variable returns to scale assumption, known as BCC model and is outlined below.

$$
\begin{aligned}
& Min\ \theta_0 \\
& Subject\ to \\
& \sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{r0};\ r = 1, 2, \ldots, s \\
& \sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta_0 x_{i0};\ i = 1, 2, \ldots, m \\
& \sum_{j=1}^{n} \lambda_j = 1 \\
& \lambda_j \geq 0;\ j = 1, 2, \ldots, n, \\
& \theta_0\ unrestricted(free)
\end{aligned}
\tag{2.4}
$$

where λ_j is the weight of the j^{th} DMU

The above two models aids in calculating efficiency scores of the DMUs and constructing the reference set formed by peers for inefficient DMUs. While ranking the DMUs based on peer count, tie may occur among the efficient DMUs. Andersen and Petersen [1] suggested the super-efficiency DEA model to break the tie.

Super-efficiency DEA models are the models when a DMU under evaluation is not included in the reference set. The CRS input oriented super-efficiency model is as follows.

$$
\begin{aligned}
& Min\ \theta^{SE} \\
& Subject\ to \\
& \sum_{\substack{j=1 \\ j\neq 0}}^{n} y_{rj}\lambda_j \geq y_{r0};\ r = 1, 2, \ldots, s \\
& \sum_{\substack{j=1 \\ j\neq 0}}^{n} x_{ij}\lambda_j \leq \theta^{SE} x_{i0};\ i = 1, 2, \ldots, m \\
& \lambda_j \geq 0;\ j = 1, 2, \ldots, n;\ j \neq 0
\end{aligned}
\tag{2.5}
$$

The VRS input oriented super-efficiency model is as follows.

$$
\begin{aligned}
& Min\ \theta^{SE} \\
& Subject\ to \\
& \sum_{\substack{j=1 \\ j\neq 0}}^{n} y_{rj}\lambda_j \geq y_{r0};\ r = 1, 2, \ldots, s
\end{aligned}
$$

$$\sum_{\substack{j=1\\j\neq 0}}^{n} x_{ij}\lambda_j \leq \theta^{SE} x_{i0};\; i = 1, 2, \ldots, m \tag{2.6}$$
$$\sum_{\substack{j=1\\j\neq 0}}^{n} \lambda_j = 1$$
$$\lambda_j \geq 0;\; j = 1, 2, \ldots, n;\; j \neq 0$$

This model provides SE score of the evaluated DMU and weights to all other DMUs in the set. The SE scores classified a set of DMUs into four groups.

(i) Set E extreme efficient ($\theta^{SE*} > 1$)
(ii) Set E' efficient but not an extreme point ($\theta^{SE*} = 1$ with zero slacks)
(iii) Set F weakly efficient ($\theta^{SE*} = 1$ but with non-zero slacks)
(iv) Set N inefficient ($\theta^{SE*} < 1$)

where ($*$) refers optimal values.

Super-efficiency Infeasibility occurs in the case of extreme efficient DMUs. Zhu [12] proposed the following necessary and sufficient condition for infeasibility.

The input oriented VRS super-efficiency model is infeasible if and only if where is the optimal value to the following model.

$$g^* = max\ g$$
$$Subject\ to$$
$$\sum_{\substack{j=1\\j\neq 0}}^{n} y_{rj}\lambda_j \geq g y_{r0};\; r = 1, 2, \ldots, s \tag{2.7}$$
$$\sum_{\substack{j=1\\j\neq 0}}^{n} \lambda_j = 1$$
$$\lambda_j \geq 0;\; j = 1, 2, \ldots, n;\; j \neq 0$$

By solving, the above model provides the optimum value of g^* which may be $<$ or > 1. $g^* < 1$ indicate infeasibility.

3. Empirical Investigation

The data considered in this study is secondary and is taken from Annual Survey of Industries (ASI) 2017-18. The data set includes 3 inputs and 2 outputs pertaining to manufacturing industries of dairy products in 23 states of India. Number of Factories (IP1), Number of Employees (IP2) and Gross value of Addition to Fixed Capital (IP3) are input variables and Total Output (OP1) and Profits (OP2) are output variables.The following tables exhibit efficiency scores, peers and ranking of DMUs based on peer count summary under (2.3) and (2.4).

TABLE 1. CCR Model - Efficiency Scores, Peers and Rank

DMU	States	Efficiency Score	Peers and its weights	Peer Count Summary	Rank
1	Andhra Pradesh	0.33	$\lambda_4 = 0.67$, $\lambda_7 = 2.67$, $\lambda_{18} = 8.23$		
2	Assam	0.02	$\lambda_4 = 0.02$, $\lambda_7 = 0.01$		
3	Bihar	0.21	$\lambda_4 = 0.42$, $\lambda_7 = 0.15$, $\lambda_{18} = 1.31$, $\lambda_{22} = 0.07$		
4	Delhi	1.00		19	1
5	Gujarat	0.20	$\lambda_4 = 5.82$, $\lambda_7 = 1.69$		
6	Haryana	0.15	$\lambda_4 = 1.29$, $\lambda_7 = 0.58$		
7	Himachal Pradesh	1.00		18	2
8	Jammu & Kashmir	0.18	$\lambda_4 = 0.03$, $\lambda_7 = 0.04$, $\lambda_{18} = 0.26$		
9	Jharkhand	0.10	$\lambda_4 = 0.14$, $\lambda_7 = 0.20$		
10	Karnataka	0.22	$\lambda_4 = 1.51$, $\lambda_7 = 3.25$		
11	Kerala	0.34	$\lambda_4 = 0.41$, $\lambda_7 = 2.14$, $\lambda_{18} = 1.78$		
12	Madhya Pradesh	0.34	$\lambda_4 = 0.51$, $\lambda_7 = 1.44$, $\lambda_{18} = 1.83$, $\lambda_{22} = 0.25$		
13	Maharashtra	0.40	$\lambda_4 = 2.99$, $\lambda_7 = 14.44$		
14	Odisha	0.15	$\lambda_4 = 0.19$, $\lambda_7 = 0.02$		
15	Puduchery	0.22	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
16	Punjab	0.06	$\lambda_4 = 0.91$, $\lambda_7 = 0.06$		
17	Rajasthan	0.18	$\lambda_4 = 0.96$, $\lambda_7 = 1.30$		
18	Sikkim	1.00		8	3
19	TamilNadu	0.12	$\lambda_4 = 1.72$, $\lambda_7 = 3.42$, $\lambda_{18} = 1.42$		
20	Telegana	0.17	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.048$		
21	Uttar Pradesh	0.35	$\lambda_4 = 2.07$, $\lambda_7 = 7.38$		
22	Uttarkhand	1.00		4	4
23	West Bengal	0.10	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		

TABLE 2. BCC Model - Efficiency Scores, Peers and Rank

DMU	States	Efficiency Score	Peers and its weights	Peer Count Summary	Rank
1	Andhra Pradesh	1.00	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		4
2	Assam	0.44	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		
3	Bihar	0.23	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
4	Delhi	1.00		15	1
5	Gujarat	1.00		2	5
6	Haryana	0.63	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.04$		
7	Himachal Pradesh	1.00		8	2
8	Jammu & Kashmir	0.46	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		
9	Jharkhand	0.26	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.04$		
10	Karnataka	0.57	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
11	Kerala	0.86	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
12	Madhya Pradesh	0.82	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
13	Maharashtra	1.00		1	6
14	Odisha	0.17	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		
15	Puduchery	0.77	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		
16	Punjab	0.07	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.04$		
17	Rajasthan	0.38	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.04$		
18	Sikkim	1.00		8	2
19	TamilNadu	0.40	$\lambda_4 = 0.16$, $\lambda_7 = 0.53$		
20	Telegana	0.35	$\lambda_4 = 0.03$, $\lambda_7 = 0.02$, $\lambda_{18} = 0.12$, $\lambda_{22} = 0.05$		
21	Uttar Pradesh	1.00		7	3
22	Uttarkhand	1.00		1	6
23	West Bengal	0.13	$\lambda_4 = 0.50$, $\lambda_7 = 1.18$, $\lambda_{18} = 1.04$		

It may be observed from table 1, that 4 out of 23 DMUs are efficient and the remaining DMUs are inefficient. The DMU 4 gets rank 1, DMU 7 gets rank 2 and so on. The results from table 2 indicate that 7 DMUs are efficient and 16 DMUs are inefficient. It may be noted that tie occurs among the ranks so to break the tie, the BCC Super-efficiency model is applied and the results are tabulated below.

Table 3. BCC SE Model - Efficiency Scores and Rank

DMU	States	Efficiency Score	Status
1	Andhra Pradesh	1.05	Extreme Efficient
2	Assam	0.44	Efficient
3	Bihar	0.23	Inefficient
4	Delhi	0.75	Inefficient
5	Gujarat	Infeasible	Extreme Efficient
6	Haryana	0.62	Inefficient
7	Himachal Pradesh	3.93	
8	Jammu & Kashmir	0.46	Inefficient
9	Jharkhand	0.26	Inefficient
10	Karnataka	0.57	Inefficient
11	Kerala	0.86	Inefficient
12	Madhya Pradesh	0.82	Inefficient
13	Maharashtra	Infeasible	Extreme Efficient
14	Odisha	0.17	Inefficient
15	Puduchery	0.77	Inefficient
16	Punjab	0.07	Inefficient
17	Rajasthan	0.38	Inefficient
18	Sikkim	6.85	Extreme Efficient
19	TamilNadu	0.40	Inefficient
20	Telegana	0.35	Inefficient
21	Uttar Pradesh	1.38	Extreme Efficient
22	Uttarkhand	1.72	Extreme Efficient
23	West Bengal	0.13	Inefficient

From the table, it can be seen that 7 DMUs are extreme efficient and belongs to set E and 16 DMUs are inefficient and are members of set N. It is known that infeasibility occurs among the extreme efficient DMUs and so there are two DMUs namely Gujarat and Maharashtra, which are infeasible. Thus, the necessary and sufficient condition of infeasibility is validated in the following table.

Table 4. Necessary and Sufficient Condition for infeasibility

DMU	**States**	**Status**	g^*
1	Andhra Pradesh	Extreme Efficient	3.9934676
2	Assam	Inefficient	357.3062969
3	Bihar	Inefficient	12.0790495
4	Delhi	Inefficient	5.8826749
5	Gujarat	Extreme Efficient	**0.6048637**
6	Haryana	Inefficient	4.3526479
7	Himachal Pradesh	Extreme Efficient	14.8561869
8	Jammu & Kashmir	Inefficient	144.9488611
9	Jharkhand	Inefficient	33.6897782
10	Karnataka	Inefficient	2.7719344
11	Kerala	Inefficient	6.1747341
12	Madhya Pradesh	Inefficient	6.5427335
13	Maharashtra	Extreme Efficient	**0.5163855**
14	Odisha	Inefficient	31.0845119
15	Puduchery	Inefficient	129.8273618
16	Punjab	Inefficient	6.4506234
17	Rajasthan	Inefficient	4.9466388
18	Sikkim	Extreme Efficient	128.3417850
19	TamilNadu	Inefficient	2.4539502
20	Telegana	Inefficient	7.8194779
21	Uttar Pradesh	Extreme Efficient	1.6714265
22	Uttarkhand	Extreme Efficient	25.8591336
23	West Bengal	Inefficient	22.4939239

The optimum value of objective function which is less than one ($g^* < 1$) confirms infeasibility. From the above table, it is observed that the optimum value of g^* confirms the infeasibility of Gujarat and Maharashtra. Then, the ranking of DMUs, excluding the infeasible units, based on super-efficiency scores is given below:

Table 5. Ranking of DMUs based on super-efficiency scores

DMU	**States**	**Efficiency Score**	Rank
1	Andhra Pradesh	1.05	5
7	Himachal Pradesh	3.93	2
18	Sikkim	6.85	1
21	Uttar Pradesh	1.38	4
22	Uttarkhand	1.72	3

The above table indicates Sikkim stood rank 1, Himachal Pradesh gets rank 2 and so on.

4. Conclusion

CCR and BCC DEA models are applied to the Dairy Products data and the efficient DMUs and peers are identified. It is observed that 4 DMUs and 8 DMUs are efficient under CCR and BCC models respectively. In BCC model, when the efficient DMUs are ranked, tie occurs. The super-efficiency model is applied to break the tie and found that 7 DMUs are extreme efficient and among them two are infeasible. The infeasibility of the two DMUs was confirmed by the necessary and sufficient condition for infeasibility. Excluding the infeasible units, the remaining 5 DMUs are ranked and the following observations are made on status comparison of the models.

DMU 4, that is Delhi, is ranked 1 under CCR and BCC models but becomes inefficient when superefficiency model is applied. On the other hand Himachal Pradesh stands rank 2 under all the three models. Sikkim secures 1^{st}, 2^{nd} and 3^{rd} rank in BCC super-efficiency, BCC and CCR model respectively. Uttar Pradesh and Andhra Pradesh, which were inefficient under CCR model, become efficient under BCC and BCCSE model. Uttarkhand secures 4^{th}, 6^{th} and 3^{rd} rank in the three models respectively.

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