Supply Chain Pessimistic Efficiency Evaluation using a Modified Data Envelopment Analysis Model

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Abstracts: **Estimating supply chain performance is a complicated decision making problem for managers. Exaggerating the performance places the results of the performance evaluation and its application at risk, because it leads to shortfall of improvement strategies for the companies. A pessimistic efficiency evaluation point of view for the supply chain gives a safe margin for improvement. This paper compares the efficiency scores of the Banker, Charnes & Cooper (BCC) model and a modified Data envelopment (DEA) model to highlight the exaggerated units. The results show that some models exaggerate the performance of some units, especially the weak efficient and inefficient units which compare by these units. The contribution of this study suggests a more robust model into the DEA literature for efficiency evaluation of supply chain, to avert the problem of improvement shortfall as a result of efficiency exaggeration by some models.**

Keyword: Supply chain, Data envelopment analysis, Pessimistic efficiency, BCC model, modified DEA model

1. Introduction

Globalization has led to the dependence on supply chain as a method for organizations to achieve its goal of profit maximization. Companies now rely on systematic design of their processes to have competitive edge. Supply and demand activities, manufacturing capacity, logistics and procurement, customer experience, outsourcing, inventory and other activities necessary for customer satisfaction, which are within the supply chain context contributes to that target. For a supply chain to be successful, cross functional integration and marketing are critical for its success [12]. Appropriate utilization of resources and infrastructure is a fundamental aspect of supply chain management. The correct amount of resources allocated to the right product, at the right time are also important facets of a supply chain. Multinationals and local organizations rely on supply chain to show their quality of service. Any supply chain that is capable of balancing resources to achieve the target outcome is considered efficient. The competitiveness of a firm can be increased by improving their supply chain activities [16]. Any attempt to make a supply chain more efficient is dependent on multiple factors, however, identifying the correct amount of resources towards achieving the target is imperative, and this is where efficiency analysis of the supply chain comes in. Fortunately, data envelopment analysis (DEA) provides a nonparametric technique that evaluates the efficiency of entities known as decision making units (DMUs) with multiple inputs and outputs. DEA was introduced by [4] by presenting the CCR model based on [8]. It was later modified by [1] in the BCC model. DEA has evolved to become one of the most salient techniques for performance measurement problems with multiple applications in finance, energy, airports and health etc. due to its robustness.

A good amount of researches have concentrated on the performance of supply chain, many of which used DEA models such as the CCR and BCC models. However, the models used in these researches exaggerate the efficiency values of the weak efficient and highly inefficient DMUs. This exaggeration is of serious consequence to management when decisions are made based on the efficiency scores. To nullify this drawback of exaggeration by these models, this study applies a modified DEA model proposed by [7], which identifies the weak efficient and highly inefficient DMUs by assigning their real efficiency scores, while maintaining the efficiency score of DMUs located at the strong part of the efficiency frontier, or compared to those located at the strong part of the frontier. The motivation of this study is that, achieving the actual value for an efficiency evaluation is equally as important as the evaluation itself, because misrepresentation of a firm's value can have devastating impact on the entire business. It is better to improve performance with a worst case scenario assumption than assuming an exaggerated performance status. A numerical example of 29 pharmaceutical companies in India used by [15] is evaluated using eight inputs and two outputs. The rest of the paper is organized as follows: section 2 gives a literature review of DEA in supply chain. The methodology is explained in section 3. Empirical example and discussion is made in section, and the paper is concluded in section 5. Simulation of the efficiency evaluation is performed with the WinQsb linear and integer programming software version 2.0.

2. Literature Review

Management thinker Peter Drucker said "you cannot manage what you cannot measure". This translates that, success is not guaranteed unless the performance is tracked and measured, and efficiency evaluation is an important method of success measurement. Efficiency evaluation of an organization can be made for different purposes which include, understanding customer requirements, identifying problems and planning improvement strategies amongst others. The primary aim of efficiency measurement is to evaluate, control and improve operations processes [9]. Supply Chain Management (SCM) involves coordinating the flow of information, goods, services and finance between the supply chain members [17].

A considerable amount of studies have been made on performance measurement of supply chain, and DEA-technique has been utilized for some of them, [14] used DEA to compare suppliers for supplier selection: their selection of inputs and outputs was based on a manufacturing firm. They used a simplified DEA model to compare suppliers' performance before selection. [23] used DEA to measure internal supply chain performance. [13] developed several DEA based approaches for characterizing and measuring supply chain efficiency when intermediate measures are incorporated into the performance evaluation. [20] use DEA to evaluate the sustainability of supply chain networks. [21] used a two-stage DEA model for measuring performance in three-level supply chains, in their analysis; they concluded that a chain is comprehensively efficient if and only if there is efficient relationship between supply chain members. [11] Performed an internal supply chain efficiency evaluation in a dynamic environment for pharmaceutical supply chain in India. [5] Evaluated the efficiency of different public pharmaceutical products supply chain using DEA, they constructed an aggregated metric's that supply chain of pharmaceutical products can be characterized. They also estimated the input adjustment necessary to make an inefficient chain efficient. [19] used an integration of network DEA and Balance score card approach to evaluate the supply chain performance of the Iranian food industry. Their study focus on the relationship between the four perspectives of the balance score card approach, especially the returnable one. A new approach was developed by [18] for determining decoupling points regarding market and customer demands, considering the internal capabilities of the supply chain, with the main purpose of increasing the chain profit and satisfying customers, using lean and agile criteria, they determine the efficiency and effectiveness of supply chain. They indicated that decoupling points can be considered as the borderline between two strategies of lean and agile production. A composite supply chain efficiency model (CSCEM) was proposed by [10], to assist the South African businesses compete with international businesses by improving their supply chain efficiency, variables identified as deficient areas by the supply chain were used. Now assuming the above mentioned literature efficiency scores are exaggerated by the models for the evaluated supply chains. The proposed improvement strategies after the efficiency evaluation will not live up to the intended target.

3. Methodology

There are two criteria used in SCM, namely the cost minimization criteria [3] and profit maximization criteria [6]. SCM has a controlling factor on the survival or failure of a business or organization [22]. Poor performance of a supply chain can be attributed to either lack of measurement system or incorrect performance evaluation. The aspect of incorrect performance evaluation provides management with misleading solution and approaches towards performance improvement. Organizations and businesses need to apply a pessimistic (worst case scenario) approach when executing performance evaluation. This will create a safe margin for error when implementing improvement strategies.

Conventional efficiency definition is as follows: [*Output/Input]*. This definition becomes ineffective when there are multiple inputs and outputs, like the case of supply chain. A suitable replacement is using weighted cost approach, which is: [*weighted sum of outputs/weighted sum of inputs]*. The problem with this method is that, it assumes that all the weights are uniform.

DEA calculates the relative efficiencies of DMUs with multiple inputs and outputs. The efficiency of each DMU is measured in comparison to other DMUs. Generally, the efficiency score of a DMU is defined as the weighted sum of outputs divided by the weighted sum of inputs, while the weights are assigned. The weights are computed by giving the highest possible score to a DMU while maintaining the efficiency scores of all DMUs less than or equal to the one under the same set of weights. The BCC model frontier of DEA has a concave characteristic with regards to its production possibility set (PPS). The PPS of the BCC model which is denoted by T_c has the following properties:

(P1) All observed input and output (X_j, Y_j) included in T_C ($j= 1,\dots, n$)

(P2) If the inputs and outputs (x_j, y_j) belongs to T_C , then the convex combination of these data $(\sum_{j=1}^{n} \lambda_j X_J, \sum_{j=1}^{n} \lambda_j Y_j)$, $\sum_{j=1}^{n} \lambda_j = 1$ $\lambda_j \geq 0$ j=1, 2,…, n also belongs to T_C

(P3) For all inputs and outputs (X, Y) included in T_C any combination of input and output $(\bar{X}, \bar{Y})$ with $\bar{X} \geq X$ and $\bar{Y} \leq Y$ belongs to T_C.

(P4) All linear combination of inputs and outputs in T_C are included in T_C

[1] proof that by using the mentioned properties of T_C defined by:

$T_C = \{(X,Y) | X \geq \sum_{j=1}^{n} \lambda_j X_j, Y \leq \sum_{j=1}^{n} \lambda_j Y_j, \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0, \forall j\}$ (1)

For evaluating the efficiency of DMU_k which belongs to PPS (T_C) in output orientation, it should find the maximum value of θ (efficiency score) in a manner that $(x_k, \theta y_k) \in \mathrm{T_c}$. The linear program derived from these properties in output orientation form is as follows:

$$\begin{aligned}
&Max \quad \theta \\
&subject \quad to \\
&\sum_{j=1}^{n} \lambda_j X_j \leq X_k \\
&-\sum_{j=1}^{n} \lambda_j Y_j + \theta Y_k \leq 0 \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0 \qquad j = 1, \dots, n
\end{aligned} \tag{2}$$

Model (3) illustrates the dual of model (2) as follows:

$$\begin{aligned}
&Min \sum_{i=1}^{m} v_i x_{ik} + v_0 \\
&subject\ to \\
&\sum_{r=1}^{t} u_r y_{rk} = 1 \\
&\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{t} u_r y_{rj} + v_0 \geq 0 \qquad j = 1, \dots n \\
&v_i \geq 0 \qquad i = 1, \dots, m \\
&u_r \geq 0 \qquad r = 1, \dots, t \\
&v_0 \ \ free
\end{aligned} \tag{3}$$

Model (3) is the BCC Model of [1]. The modified DEA model used in this study was introduced by [6], it is a modification on the "BCC model" model (3). The modification examines the weak part of the efficiency frontier were the weak efficient DMUs and other DMUs that get their efficiency value when compared to the weak part of the frontier are located. This is achieved by using facet analysis of [2] as shown in model (4) on the efficient DMUs evaluated by model (3). The modification is made by placing an upper bound "η" from equation (5) on the free variables v_0 of the BCC model in model (3). The modified DEA model is shown in model (6).

$$\begin{aligned}
&v_0^+ = Max v_0 \\
&subject to \\
&\sum_{i=1}^{m} v_i x_{kj} + v_o = 1 \\
&\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{t} u_r y_{rj} + v_0 \geq 0 \qquad j = 1, \dots, n \\
&\sum_{r=1}^{t} u_r y_{kj} = 1 \\
&u_r \geq 0 \qquad for\ r = 1, \dots, t \\
&v_i \geq 0 \qquad for\ i = 1, \dots, m \\
&v_0 \quad free
\end{aligned} \tag{4}$$

$$\eta = Min \ \{v_0^+ \mid v_0^+ \neq -\infty \ for \ \ efficient \ \ DMUs\} \tag{5}$$

Where u_r is the weight of output r, v_i is the weight of input i , y_{rj} is the amount of r output for DMU j, x_{ij} is the amount of i input for DMU j, t is the number of outputs, m is the number of input. n is the number of DMUs, ε^* is the

$$\begin{aligned}
&\varepsilon^* = Min \sum_{i=1}^{m} v_i x_{ik} + v_o \\
&subject \ \ to \\
&\sum_{r=1}^{t} u_r y_{rj} = 1 \\
&\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{t} u_r y_{rj} + v_0 \geq 0 \qquad j = 1, \dots, n \\
&u_r \geq 0 \qquad for\ r = 1, \dots, t \\
&v_i \geq 0 \qquad for\ i = 1, \dots, m \\
&v_0 \geq \eta
\end{aligned} \tag{6}$$

efficiency score from the modified DEA model (output orientation). A DMU k is deemed efficient if the objective function is equal to one and inefficient if less than one.

4. Empirical Example and Discussion

Table 1 gives the description of the list of inputs and outputs used in the analysis from [15]. Table 2 shows the DMUs labelled P01 to P29 representing the pharmaceutical companies in India with eight inputs and two outputs as classified in Table 1. Table 3 shows the comparison between the efficiency of the BCC model and modified DEA model. The upper bound for "η" in the modified DEA model is (+0.44) after using model (4) and equation (5) on all the efficient DMUs.

Table 1: Classification of Inputs/Output

Inputs	Outputs
X_1: Internal Manufacturing Capacity (IMC) X_2: Supply chain cost (SC) [Rs. In lakhs] X_3: Working Capital (WC) [Rs. In lakhs] X_4: Invested Capital (IC) [Rs. In lakhs] X_5: Number of Employees (NE) X_6: Wages to Workers (WW) [Rs. In lakhs] X_7: Materials Consumed (MC) [Rs. In lakhs] X_8: Fuels Consumed (FC) [Rs. In lakhs]	Y_1: Net Value Added due to supply chain (NVA) [Rs. In lakhs] Y_2: Net Income (NI) [Rs. In lakhs]

Table 2: Input/Output data

DMUs	x1	x2	x3	x4	x5	x6	x7	x8	y1	y2
P01	682	13370	14629	34049	80384	3046	1819	31941	15695	13289
P02	800	14602	16654	36425	85559	7850	39386	49408	18557	21653
P03	866	15791	19878	39528	85603	3798	2948	44231	24808	21653
P04	918	17485	22865	45312	103468	4356	3286	52416	27041	23753
P05	1043.54	25926.44	29277.7	62355.6	113889.1	6347.548	4474.414	67180.3	31588.02	27000.81
P06	1219.458	32886.27	36425.09	78678.88	126789.8	8064.555	6118.149	87730.82	33183.87	27273.99
P07	1463.03	48621.55	48412.9	109618.9	145643.5	10969.61	9678.177	120682.3	37143.91	29137.97
P08	1253.418	43599.54	42111.49	98570.89	125700.5	10177.62	9073.948	110564.1	47580.52	39171.38
P09	1187	44194	42639	101515	120396	10867	8619	117083	63307	53079
P10	1591.744	65135.01	63004.67	150729.5	156572.4	15787.82	12437.64	175519.6	57120.2	44540.19
P11	1294.544	55761.96	57862.96	127493.7	126839.4	12773.04	10194.86	148486	76270.44	51667.06
P12	1374	62117	46735	130898	120174	15160	1921	11938	6600.07	13474
P13	1497	73434	55204	155980	134779	18734	1985	15437	10679	17609
P14	1554	87577	72869	201616	135384	20356	15752	246382	101463	80613
P15	1105.987	104327	54167.57	168880.4	101967.3	9311.04	13332.43	230342.2	34346.54	16549.99
P16	1007.3	106240.7	41592.15	155570.3	83280.97	7094.861	13836.86	155600.3	51980.68	31798.51
P17	1261.485	116301.6	62121.56	179343.7	101551.6	9170.063	16646.79	162168.9	61581.27	35849.97
P18	1496.279	180235	120651.4	292782.1	122377.3	16622.72	25245.43	325385.5	89444.06	44670.56
P19	1968.829	312556.3	138548.3	443374.2	132094	18483.44	34181.46	380080.9	103531.9	54816.81
P20	2845.766	440808.4	243977.3	645401.1	168405.8	25547.08	49308.44	454865.9	154441.8	50278.68
P21	3293.549	594489.2	228029.7	809059.5	171165	27979.91	55783.36	524551.4	175744.4	75499.46
P22	3855	982507	206070	1186858	132180	24320	51959	690302	257688	176840
P23	4046	719461	255442	937341	134861	136618	9292	63597	57905	65168
P24	587	230394.9	177104	342808.2	47972.94	17528.92	18909.9	496375.5	235769	26661
P25	608	398729.6	170768.6	574175.9	44295.87	17207.48	22063.02	615935	125600	49463
P26	640	228821	150160	354173	36194	16142	19060	546393	107364	54759
P27	642	303888.9	89306	431703.2	39541	16541.75	22097	629821.8	90702	22399
P28	621	591	285636	116035	25592	1536	777	4116	616915	598
P29	12656	3303003	600909	4055974	472330	140109	1028465	1716212	1062762	868909

Table 3: BCC and Modified DEA efficiency

DMUs	BCC	Modified DEA
P01	100	100
P02	100	100
P03	100	100
P04	100	100
P05	89.07	89.07
P06	69.37	69.37
P07	54.19	54.14
P08	78.05	78.02
P09	100	100
P10	67.9	67.86
P11	88.66	88.66
P12	100	100
P13	100	100
P14	100	100
P15	38.15	36.75
P16	97.78	94.08
P17	71.24	71.24
P18	58.82	58.44
P19	56.89	56.49
P20	46.28	44.82
P21	57.28	55.75
P22	100	100
P23	100	100
P24	100	100
P25	100	100
P26	100	100
P27	100	100
P28	100	100
P29	100	100

The proposed modified DEA model for supply chain efficiency evaluation in this paper highlights the DMUs that are exaggerated by the BCC model. The DMUs that are not exaggerated remain the same as shown by the BCC model when the modified DEA model is applied, and those that are exaggerated change their efficiency scores. Table 3 shows that DMUs P07, P08, P10, P15, P16, P18, P19, P20 and P21 are exaggerated and are more inefficient than expressed by the BCC model. Therefore, the pharmaceutical companies identified by these DMUs need to take special measures to improve their efficiency.

Table 4: Weights of Inputs/Outputs for Modified DEA model

DMUs	x1	x2	x3	x4	x5	x6	x7	x8	y1	y2
P01	0	0	8.55	0	39.19	0	8.08	15.76	0	65.39
P02	0	0	36.31	0	0	0	3.97	0	0	40.13
P03	0	165.03	0	0	0.31	0	1.68	0	0	40.13
P04	0	151.87	0	0	0	0	1.26	0	0	36.58
P05	0	0.81	0	0	0	0.15	207.05	0	0.59	31.61
P06	0	0.8	0	0	0	0.15	204.83	0	0.59	31.27
P07	0	7.94	0	0	0	19.68	2.94	0	0.62	29.17
P08	0	7.43	0	0	0	14.64	0	0	0	22.18
P09	0	4.31	0	0	0	0	0	11.93	0	16.37
P10	0	14.75	0	0	0	0	0	5.67	1.04	18.41
P11	0	5.52	0	0	0	6.18	5.77	0	0.82	15.83
P12	0	0	0.03	0	0	7.01	0	62.56	0	64.49
P13	0	2.28	0	0	0	0	319.63	0	0.93	48.88
P14	0	1.23	0	0	0	0	6.31	3.76	0.58	10.18
P15	10.82	0	13.4	0	9.82	0	28	0	9.5	36.38
P16	0	0	10.72	0	13.11	0	5.56	0	0	27.33
P17	0	7.98	0.42	0	4.65	8.57	3.15	0	0	24.24
P18	6.81	1.95	0	0	0	4.99	6.3	0	0.75	18.22
P19	5.57	1.59	0	0	0	4.08	5.15	0	0.61	14.9
P20	0	4.69	0	0	0	0	11.52	0	1.82	12.72
P21	0	3.34	0	0	0	0	8.2	0	1.29	9.05
P22	0	1.74	0	0	1.04	0	2.34	0	0.22	4.65
P23	0	2.14	0	0	0	0	0	11.07	0	13.33
P24	33.3	0	3.87	0	0	0	0	0	3.07	10.41
P25	42.35	0	0	0	0	0	0	0	0	17.57
P26	0	12.74	0	0	4.84	0	0	0	0	15.87
P27	0	0.32	9.34	0	10.46	0	15.58	0	5.82	19.53
P28	0	0	0	0	0	0	3.31	0	1.72	0
P29	0	0	0	0	0	0	0.89	0	0.19	0.53
Average	3.408621	13.74	2.849655	0	2.876552	2.256897	29.36276	3.818966	1.04	23.97759

The evaluation also shows that all the efficient companies are truly efficient, and most of the inefficient companies are exaggerated. However, it is worth mentioning that in some cases, the efficient DMUs will change their efficiency scores and become inefficient when the modified DEA model is applied. The pessimistic nature of the Modified DEA model suggests that more resources should be allocated to the inefficient DMUs to improve their efficiency, by studying the reasons for inefficiency to prevent future occurrences. If decisions are made based on the results of the BCC model, it is possible that the improvement will fall short of the actual requirement. And if investment decisions are made, the returns will be short of actual expectation because their performances are exaggerated.

Weight distribution in DEA shows the level of contribution of that variable to the efficiency of the DMU. The average weight distribution gives an aggregate level of importance of that variable to the overall efficiency of the production set. Table 4 shows the weight distribution of the evaluated DMUs and concludes that the omission of X_4 (Invested capital) will not affect the efficiency of the companies. Contrary to X_4, X_7 (Materials consumed) and Y_2 (Net Income) contributes the most to the efficiency of the industry from their average weight distribution. This is logical because, the pharmaceutical industry in India is a quantitative (bulk production) industry. Therefore, the inefficient companies need to focus on producing more products, there by consuming more materials which directly increases the Net value added to the supply chain Y_1 and Net income Y_2.

5. Conclusion

This study utilizes a Modified DEA model to evaluate the relative efficiency of pharmaceutical companies supply chain from a pessimistic model perspective. The proposed modified DEA model is compared with the BCC model to highlight the exaggerated DMUs. These exaggerated efficiencies are critical for decision making. The pessimistic nature of the model preserves the efficiency scores of the strong hyperplane DMUs, i.e the highly efficient DMUs and other DMUs compared to them. The modified DEA model shows that critical observation of the weak performing companies should be performed using the conclusion of the weight distribution. The findings of this study are especially significant to the management of the pharmaceutical companies because, the exaggeration of performance (efficiency) often leads to shortfall of improvement, when the improvement strategies are based on the optimistic evaluation. Furthermore, the weights distribution calculated for the variables used shows the important factors that contributes the most to the efficiency of the supply chain. Investors and decision makers can use the weight distribution as reference for investment, and the management can develop improvement strategies based on the important variables. Moreover, this study suggests the use of the Modified DEA model to assess the performance of supply chain. The modified DEA model proposed in this paper is based on the variable return to scale (VRS) assumption in DEA, as a direction for future research, exploring the constant return to scale (CRS) assumption in DEA with the proposed modified model should give more information to the management.

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