Research Article

A Data Envelopment Analysis Approach to Supply Chain Efficiency

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Supply chain management is an important competitive strategies used by modern enterprises. Effective design and management of supply chains assists in the production and delivery of a variety of products at low costs, high quality, and short lead times. Recently, data envelopment analysis (DEA) has been extended to examine the efficiency of supply chain operations. Due to the existence of intermediate measures, the usual procedure of adjusting the inputs or outputs, as in the standard DEA approach, does not necessarily yield a frontier projection. The current paper develops a DEA model for measuring the performance of suppliers and manufacturers in supply chain operations. Additive efficiency decomposition for suppliers and manufacturers in supply chain operations is proposed.

1. Introduction

Data envelopment analysis (DEA), originated from the work of Charnes et al. [1], is a linear programming, nonparametric technique used to measure the relative efficiency of peer decision making units with multiple inputs and outputs. This methodology has been applied in a wide range of applications over the last three decades, in setting that include banks, hospitals, and maintenance. See for instances Amirteimoori and Emrouznejad [2], Amirteimoori and Kordrostami [3], Amirteimoori [4], and Cooper et al. [5]. Recently, a number of studies have looked at production processes that have two-stage network structure, as supply chain operations. Due to the existence of intermediate measures, the usual procedure of adjusting the inputs or outputs, as in the standard DEA approach, does not necessarily yield a frontier projection. Many researchers have applied standard DEA models to measure the performance of supply chain members. See for instances, Weber and Desai [6], Easton et al. [7], Talluri and Baker [8], Liang et al. [9], Chen et al. [10], and Chen [11].
Weber and Desai [6] employed DEA to construct an index of relative supplier performance. Färe and Grosskopf [12] developed a network DEA approach to model the general multistage processes. Easton et al. [7] suggested a DEA model to compare the purchasing efficiency of firms in the petroleum industry. Talluri and Baker [8] proposed a multiphase mathematical programming approach for effective supply chain design. Their methodology applies a combination of multicriteria efficiency models, based on game theory concepts, and linear and integer programming methods. Liang et al. [9] and Chen et al. [10] developed several DEA-based approaches for characterizing and measuring supply chain efficiency when intermediate measures are incorporated into the performance evaluation. Chen [11] proposed a structured methodology for supplier selection and evaluation in a supply chain, to help enterprises establish a systematic approach for selecting and evaluating potential suppliers in a supply chain. Feng et al. [13] defined two types of supply chain production possibility sets, which are proved to be equivalent to each other.

Some of the above-mentioned studies treat the supply chain as a black-box and do not consider the intermediate measures. However, in all studies, the treatment to the intermediate measures is ambiguous. Moreover, some of the above-mentioned studies are not applicable in a more complex supply chain or a network structured case.

If we treat the supply chain operation as a black-box, ignoring the intermediate measure may yield an efficient supply chain with inefficient supplier and/or manufacturer. In the proposed model in this paper, the intermediate measure is considered as a free variable, and it will be reduced to make the whole supply chain as efficient.

The paper develops a DEA model for measuring the performance of suppliers and manufacturers in supply chain operations. Additive efficiency decomposition for suppliers and manufacturers in supply chain operations is proposed and the DEA frontier points for inefficient supply chain members are determined.

The structure of this paper is the following. In Sections 2 and 3, the problem statement and axiomatic foundation are, respectively, presented. In Section 4, the proposed approach is presented. Section 5 applies the proposed model on a numerical example taken from Liang et al. [9]. The last section summarizes and concludes.

2. Problem Statement

Consider a two-stage supply chain, for example, supplier-manufacturer supply chain as shown in Figure 1.

Suppose we have \( n \) homogeneous supply chain operations. Each supply chain observation is considered to be a DMU. It is assumed that each supplier \( S_j \) in DMU \( j : j = 1, \ldots, n \) has \( m \) inputs \( x_{ij} : i = 1, \ldots, m \) and \( s \) outputs \( y_{rj} : r = 1, \ldots, s \). These \( s \) outputs...
can become the inputs to the manufacturer $M_j$. The manufacturer $M_j$ has its own inputs $z_{dj}: d = 1, \ldots, D$. The final outputs from manufacturer are $q_{lj}: l = 1, \ldots, L$.

3. Axiomatic Foundation

Let $T_S$ be the production possibility set of technology under consideration for the supplier $S$. We postulate the following:

**P1: Feasibility of Observed Data**

$(x_j, y_j) \in T_S$ for any $j = 1, 2, \ldots, n$.

**P2: Unbounded Ray**

$(x, y) \in T_S$ implies $\lambda (x, y) \in T_S$ for any $\lambda \geq 0$.

**P3: Convexity**

Let $(x', y') \in T_S$ and $(x'', y'') \in T_S$. Then, for any $\lambda \in [0, 1]$, the unit $\lambda(x', y') + (1 - \lambda)(x'', y'') \in T_S$.

**P4: Free Disposability**

(a) $(x, y) \in T_S$, $x' \geq x$ and $y' \leq y$, implies $(x', y') \in T_S$

or

(b) $(x, y) \in T_S$, $x' \geq x$ and $y' \geq y$, implies $(x', y') \in T_S$.

**P5: Minimal Extrapolation**

For each $T'$ satisfying in the axioms P1–P4, we have $T_S \subseteq T'$.

Now, an Algebraic representation of the PPS of the technology $T_S$, satisfying the axioms P1–P5, is given.

**Theorem 3.1.** The PPS $T_S$, which satisfies the axioms P1–P5, is defined as

$$T_S = \left\{ (x, y) : x \geq \sum_{j=1}^{n} \lambda_j x_j, \left( y \leq \sum_{j=1}^{n} \lambda_j y_j \text{ or } y \geq \sum_{j=1}^{n} \lambda_j y_j \right), \lambda_j \geq 0, j = 1, 2, \ldots, n \right\}.$$ \hfill (3.1)

**Proof.** The proof is clear.

Also, let $T_M$ be the production possibility set of technology under consideration for the manufacturer $M$. Again, to determine the technology of the manufacturer $M$, we postulate the following:
P’1: Feasibility of Observed Data
\((y_j, z_j, q_j) \in T_M\) for any \(j = 1, 2, \ldots, n\).

P’2: Unbounded Ray
\((y, z, q) \in T_M\) implies \(\lambda (y, z, q) \in T_M\) for any \(\lambda \geq 0\).

P’3: Convexity
Let \((y', z', q') \in T_M\) and \((y'', z'', q'') \in T_M\). Then, for any \(\lambda \in [0, 1]\) the unit \(\lambda (y', z', q') + (1 - \lambda)(y'', z'', q'') \in T_M\).

P’4: Free Disposability
\((y, z, q) \in T_M\), \(y' \geq y\), \(z' \geq z\) and \(q' \leq q\), implies \((y', z', q') \in T_M\) or
\((y, z, q) \in T_M\), \(y' \leq y\), \(z' \geq z\) and \(q' \leq q\), implies \((y', z', q') \in T_M\).

P’5: Minimal Extrapolation
For each \(T'\) satisfying in the axioms P1–P4, we have \(T_M \subseteq T'\).

Similarly, an Algebraic representation of the PPS of the technology \(T_M\), satisfying the axioms P’1–P’5, is given.

**Theorem 3.2.** The PPS \(T_M\), which satisfies the axioms P’1–P’5, is defined as

\[
T_M = \left\{ (y, z, q) : \begin{array}{l}
y \geq \sum_{j=1}^{n} \lambda_j y_j \text{ or } y \leq \sum_{j=1}^{n} \lambda_j y_j \\
z \geq \sum_{j=1}^{n} \lambda_j z_j, \quad q \leq \sum_{j=1}^{n} \lambda_j q_j, \quad \lambda_j \geq 0, \quad j = 1, 2, \ldots, n
\end{array} \right\},
\]

(3.2)

**Proof.** The proof is clear. \(\square\)

In the definition of \(T_M\) and \(T_M\), the intermediate measure \(y\) can increase or decrease. In the proposed model, this measure is simultaneously reduced for supplier and manufacturer to achieve a steady state.

**4. The Proposed Model**

In applying the model described herein, attention is paid to additive model. Consider the assessment of DMU\(_0\) (supplier \(S_0\) and manufacturer \(M_0\)) in additive form. In the assessment of supplier \(S_0\), the output measure \(y\) should be increased. On the other hand, this measure is considered as input to the manufacturer \(M_0\) and it should be decreased. If we treat the supply chain operation as a black-box, ignoring the intermediate measure \(y\) may yield an efficient
supply chain with inefficient supplier and/or manufacturer. In the model we proposed, the intermediate measure $y$ is considered as a free variable, and it will be reduced (increased or decreased) to make the overall system as efficient.

Based on the comments made above, and taking into account Theorems 3.1 and 3.2, the $o$-th supply chain’s performance can be obtained as the optimal value of the following two models:

\[
\begin{align*}
\min_{s} & \quad s^{(1)} + s^{(2)} + s^{(3)} + s^{(4)} + s^{(5)} \\
\text{s.t.} \quad n & \sum_{j=1}^{n} \lambda_j x_j + s^{(1)} = x_o, \\
& \sum_{j=1}^{n} \lambda_j y_j + s^{(2)} = y_o, \\
& \sum_{j=1}^{n} \mu_j z_j + s^{(3)} = z_o, \\
& \sum_{j=1}^{n} \mu_j q_j - s^{(4)} = q_o,
\end{align*}
\]

(4.1)

\[
\begin{align*}
\lambda_j, \mu_j & \geq 0, \quad j = 1, 2, \ldots, n, \\
s^{(1)}, s^{(3)}, s^{(4)} & \geq 0, \\
s^{(2)} & \text{ is unrestricted in sign.}
\end{align*}
\]

Obviously, this problem is feasible and the optimal objective value to this problem is bounded. We, therefore, provide an alternative definition for supply chain efficiency as follows.

**Definition 4.1.** Supplier $o$ is said to be additive efficient if and only if $s^{(1)} + s^{(2)} = 0$.

**Definition 4.2.** Manufacturer $o$ is said to be additive efficient if and only if $s^{(2)} + s^{(3)} + s^{(4)} = 0$.

Clearly, $o$-th supply chain is said to be overall efficient if and only if $e_o = 0$.

For an inefficient supplier $S_o(x_o, y_o)$, we have

\[
\begin{align*}
x_o &= \sum_{j=1}^{n} \lambda_j x_j - s^{(1)}, \\
y_o &= \sum_{j=1}^{n} \lambda_j y_j + s^{(2)}.
\end{align*}
\]

(4.2)

On the other hand, for an inefficient manufacturer $M_o(y_o, z_o, q_o)$, we have

\[
\begin{align*}
y_o &= \sum_{j=1}^{n} \mu_j y_j + s^{(2)}, \\
z_o &= \sum_{j=1}^{n} \mu_j z_j - s^{(3)}, \\
q_o &= \sum_{j=1}^{n} \mu_j q_j + s^{(4)}.
\end{align*}
\]

(4.3)
5. Numerical Example

To illustrate the proposed approach consider a simple example involving ten supply chains taken from Liang et al. [9]. The suppliers use three inputs $x_1, x_2,$ and $x_3$ to produce two outputs $y_1, y_2$. On the other hand, the manufacturer uses $y_1, y_2,$ and $z_1$ to generate two outputs $q_1$ and $q_2$. The data are summarized in Table 1. The results from model 1 are listed in Table 2. As the table indicates, only one supply chain, 6, is efficient in aggregate sense. Clearly, a DMU may be efficient in supplier or manufacturer only, such as in the case for members 5 and 9. The projection points are listed in Table 3.

The interpretation of our model can be illustrated by considering a specific supply chain, say supply chain 1. Both, the supplier and manufacturer in this supply chain are inefficient. The projection point to this supply chain is

$$(x_1, x_2, x_3, y_1, y_2, z_1, q_1, q_2) = (6.19, 19.34, 0.77, 24.53, 4.53, 8, 100, 29.06).$$ (5.1)
Table 3: Projection points.

<table>
<thead>
<tr>
<th>$j$</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$y_1$</th>
<th>$y_2$</th>
<th>$z_1$</th>
<th>$q_1$</th>
<th>$q_2$</th>
</tr>
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<tr>
<td>1</td>
<td>6.19</td>
<td>19.34</td>
<td>0.77</td>
<td>24.53</td>
<td>4.53</td>
<td>8</td>
<td>100</td>
<td>29.06</td>
</tr>
<tr>
<td>2</td>
<td>7.28</td>
<td>22.73</td>
<td>0.91</td>
<td>11.82</td>
<td>10</td>
<td>122.73</td>
<td>34.10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6.38</td>
<td>19.95</td>
<td>0.80</td>
<td>24.04</td>
<td>8</td>
<td>100.96</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7.27</td>
<td>22.73</td>
<td>0.91</td>
<td>21.82</td>
<td>21.82</td>
<td>10</td>
<td>122.73</td>
<td>34.10</td>
</tr>
<tr>
<td>5</td>
<td>9.73</td>
<td>30.41</td>
<td>1.22</td>
<td>15.68</td>
<td>15</td>
<td>171.44</td>
<td>44.97</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>35</td>
<td>2</td>
<td>35</td>
<td>10</td>
<td>5</td>
<td>90</td>
<td>35</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>21.88</td>
<td>0.87</td>
<td>2.5</td>
<td>32.5</td>
<td>10</td>
<td>119.80</td>
<td>32.66</td>
</tr>
<tr>
<td>8</td>
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<td>35.1</td>
<td>1.74</td>
<td>8</td>
<td>32</td>
<td>8</td>
<td>120</td>
<td>43</td>
</tr>
<tr>
<td>9</td>
<td>6.05</td>
<td>18.92</td>
<td>0.76</td>
<td>4.86</td>
<td>4.87</td>
<td>15</td>
<td>132.03</td>
<td>25.74</td>
</tr>
<tr>
<td>10</td>
<td>7.27</td>
<td>22.73</td>
<td>0.91</td>
<td>21.82</td>
<td>11.82</td>
<td>10</td>
<td>122.73</td>
<td>34.09</td>
</tr>
</tbody>
</table>

It is to be noted that the first intermediate measure should be increased from 20 to 24.53, whereas the second one should be decreased from 10 to 4.53. These reductions make the supply chain as efficient.

We used GAMS software on a Pentium 4, 512 Mbytes RAM, 2 GHz PC.

6. Conclusions

A supply chain’s performance can be overestimated if we treat the supply chain operation as a black box. Moreover, due to the existence of intermediate measures, the usual procedure of adjusting the inputs or outputs, as in the standard DEA approach, does not necessarily yield to a frontier projection. The current paper introduced the technologies used in supply chain operations. A method for determining the DEA frontier points for inefficient supplier and manufacturers in supply chain operations has been shown. The paper developed a DEA model for measuring the performance of suppliers and manufacturers in supply chain operations.

References


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