Revenue Efficiency and Revenue Malmquist Index for Centralized DMU in Different Models of DEA

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Abstract

The malmquist index is the prominent index for measuring the productivity change of DMUs in multiple time periods. In this paper, first, we compute the revenue efficiency for DMUs in Trade off models in DEA, and we obtain revenue malmquist index for DMUs in Trade off models in DEA, then with definition Centralized DMU, we compute revenue efficiency and revenue malmquist Index for Centralized DMU in different models of DEA, (variable return to scale and Trade offs technology) Numerical example is given for the purpose of illustration.

Keywords: Revenue efficiency, Centralized DMU, Trade off, Revenue malmquist index.

Introduction

Data envelopment analysis (DEA) is a mathematical programing technique that measures the relative efficiency of decision-making units (DMUs) with multiple inputs and outputs. Charnes et al.(1978) first proposed DEA as an evaluation tool to measure and compare the relative efficiency of DMUs. Their model assumed constant returns to scale (CRS, the CCR model) and the model with variable return to scale (VRS, the BCC model) was developed by Banker et al. (1984). Podinovski et al.(2004) suggests the incorporation of production trade-offs into DEA (TO) models under these circumstances, but weight restriction and trade-offs are most commonly used by decision makers. The malmquist index is the most important index for measuring the relative productivity change of DMUs in multiple time periods. For the first time, the malmquist index was introduced by Caves et.al (1982), later DEA was used by Fare, Grosskopf, Lindgren and Ross (FGLR, Fare et al.1992), and (FGNZ, Fare et al.1994) for measuring the malmquist index. They used DEA model (CCR) and VRS for computing malmquist index. Lozano and et.al (2009) defined Centralized DMU (CDMU), and they evaluated efficiency for CDMU. The structure of the paper is as follows. In section 2 we explain revenue efficiency and revenue malmquist index for DMUs in different models of DEA (CRS, VRS, TO). In the next section (3), we define Centralized DMU, which was introduced by Lozano and et.al for the first time in (2009). In section (4) and (5) we compute revenue efficiency and revenue malmquist index for Centralized DMU in different models of DEA (VRS, TO). To illustrate numerical example is mentioned in section 6. The last section summarizes and concludes.

Revenue Efficiency And Revenue Malmquist Index For DMUs In Different Models Of DEA

Assuming that there are n DMUs each with m inputs and s outputs, we evaluate the cost efficiency of DMUo o 2 {1, 2, ..., n} in the following way:

\[ p^{CRS} = \max \sum_{k=1}^{s} \beta_k y_k \]
\[ \text{s.t. } \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} \]
\[ \sum_{j=1}^{n} \lambda_j y_{kj} \geq y_k \]
\[ \lambda_j \geq 0 \]
\[ y_k \geq 0 \]

Where \( j \) is the DMU index \( j = 1, 2, ..., n \), \( k \) the output index, \( k = 1, 2, ..., s \) and \( i \) the input index \( i = 1, 2, ..., m \) ykj value of the kth output for the jth DMU, xij the value of the ith input for the jth DMU and \( P = (p_1, p_2, ..., p_s) \) is the common unit output-price or unit Revenue vector. Let the optimal solution obtained from solving model (1) be \( (Y^*, \lambda^*) \), then the revenue efficiency is defined in ratio from:

\[ ER = \frac{p^{CRS}}{p^*} = \frac{\sum_{k=1}^{s} \beta_k y_k}{\sum_{k=1}^{s} \beta_k y_k} \]

It is alleged that 0 \( \leq ER \leq 1 \); moreover, DMUo = (xo, yo) is revenue efficient if and Only if ER = 1.(For more details see Farrell(1957)). By a similar way, we can compute the revenue efficiency of DMUo in VRS model of DEA by addition a constraint of \( \sum_{j=1}^{n} \lambda_j = 1 \) to model(1) Supposing there are l Trade offs, we shall represent the Trade offs in form (Dif, Qkf) where \( i = 1, 2, ..., m \), \( k = 1, 2, ..., s \) and \( f = 1, 2, ..., l \) (for more details about Trade offs model of DEA see Podinovski (2004)). We evaluate the revenue efficiency of DMUo o 2 {1, 2, ..., n} in Trade offs model of
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DEA according to the following model:

\[
P_Y^{(C)} = \max \sum_{k=1}^{s} p_{ko} y_k
\]
\[
\text{S.t} \quad \sum_{j=1}^{n} \lambda_j x_{ij} + \sum_{f=1}^{l} \pi_f d_{ij} \leq x_{io} \quad i=1,2,\ldots,m
\]
\[
\sum_{j=1}^{n} \lambda_j y_{kj} + \sum_{f=1}^{l} \pi_f q_{kf} \geq y_k \quad k=1,2,\ldots,s
\]
\[
\lambda_j \geq 0 \quad j=1,2,\ldots,n
\]
\[
\pi_f \geq 0 \quad f=1,2,\ldots,l
\]
\[
y_k \geq 0 \quad k=1,2,\ldots,s
\]

Therefore the cost efficiency of DMUo in Trade offs model of DEA is:

\[
E_{R}^{O}(Revenue \ Efficiency) = \frac{P_{Y_0}}{P_{Y_0}} = \frac{\sum_{k=1}^{s} p_{ko} y_{ko}}{\sum_{k=1}^{s} p_{ko} y_{ko}^*} \quad (4)
\]

The computation of \(P_{Y_{t+1}}^{(C)}E_{R(t)}^{(C)}\) (DMU in period t and frontier period t) and \(P_{Y_{t}}^{(C)}E_{R(t)}^{(C)}\) (DMU in period t + 1 and frontier period t + 1) are like (1) and (2) where \((x_{ij}, y_{kj})\) and \((x_{ij}^+, y_{kj}^+)\) are substituted for \((x_{ij}, y_{kj})\) for all i, k, j. In a similar way we can compute \(E_{R(t)}^{(VRS)}, E_{R(t+1)}^{(VRS)}\) (The computation of \(P_{Y_{t+1}}^{(V)}E_{R(t)}^{(V)}\), \(E_{R(t+1)}^{(V)}\) and \(P_{Y_{t+1}}^{(V)}E_{R(t+1)}^{(V)}\) are like (3),(4) where \((x_{ij}, y_{kj})\) and \((x_{ij}^+, y_{kj}^+)\) are substituted for \((x_{ij}, y_{kj})\) for all i, k, j.

DEA model with CRS technology and input orientation, Frontier period=t+1 and DMUo in period t.

\[
P_{Y_{t}^{+1}}^{(C)} = \max \sum_{k=1}^{s} p_{ko} y_{k}^+
\]
\[
\text{S.t} \quad \sum_{j=1}^{n} \lambda_j^t x_{ij}^t \leq x_{io}^t \quad i=1,2,\ldots,m
\]
\[
\sum_{j=1}^{n} \lambda_j^t y_{kj}^t \geq y_{k}^t \quad k=1,2,\ldots,s \quad (5)
\]
\[
\lambda_j^t \geq 0 \quad j=1,2,\ldots,n
\]
\[
y_k^t \geq 0 \quad k=1,2,\ldots,s
\]

Therefore, the cost efficiency for DMUo in period t and frontier period t + 1 is:

\[
E_{R(t)}^{(C)} = \frac{\sum_{k=1}^{s} p_{ko} y_{ko}^t}{\sum_{k=1}^{s} p_{ko} y_{ko}^{t+1}} \quad (6)
\]

DEA model with CRS technology and input orientation,

\[
P_{Y_{t+1}}^{(C)} = \max \sum_{k=1}^{s} p_{ko} y_{k}^{t+1}
\]
\[
\text{S.t} \quad \sum_{j=1}^{n} \lambda_j^t x_{ij}^t \leq x_{io}^{t+1} \quad i=1,2,\ldots,m
\]
\[
\sum_{j=1}^{n} \lambda_j^t y_{kj}^t \geq y_{k}^{t+1} \quad k=1,2,\ldots,s \quad (7)
\]
\[
\lambda_j^t \geq 0 \quad j=1,2,\ldots,n
\]
\[
y_k^{t+1} \geq 0 \quad k=1,2,\ldots,s
\]

Hence, the revenue efficiency for DMUo in period t + 1 and frontier period t is:

\[
E_{R(t+1)}^{(C)} = \frac{\sum_{k=1}^{s} p_{ko} y_{ko}^{t+1}}{\sum_{k=1}^{s} p_{ko} y_{ko}^{t}} \quad (8)
\]

DEA model with Trade offs technology and input orientation

Frontier period=t + 1 and DMUo in period t.

\[
P_{Y_{t}}^{(T)} = \max \sum_{k=1}^{s} p_{ko} y_{k}^{t}
\]
\[
\text{S.t} \quad \sum_{j=1}^{n} \lambda_j^t x_{ij}^t + \sum_{f=1}^{l} \pi_f^t d_{ij} \leq x_{io}^t \quad i=1,2,\ldots,m
\]
\[
\sum_{j=1}^{n} \lambda_j^t y_{kj}^t + \sum_{f=1}^{l} \pi_f^t q_{kf}^t \geq y_{k}^t \quad k=1,2,\ldots,s \quad (9)
\]
\[
\lambda_j^t \geq 0 \quad j=1,2,\ldots,n
\]
Therefore, the revenue efficiency for DMU\(_o\) in period \(t\) and frontier period \(t+1\) is:

\[
E_{R(t)}^{t+1(TO)} = \frac{\sum_{k=1}^{s} P_{ko} y_{k}^{t+1}}{\sum_{k=1}^{s} P_{ko} y_{k}^{t}}
\]  

(10)

DEA model with Trade offs technology and input orientation

Frontier period \(t\) and DMU\(_o\) in period \(t+1\),

\[
P Y_{t+1} = \max \sum_{k=1}^{s} P_{ko} y_{k}^{t+1}
\]  

(11)

\[
\text{s.t. } \sum_{j=1}^{n} \lambda_{j} d_{ij} + \sum_{f=1}^{l} \pi_{f} y_{k}^{t} \geq x_{it}^{t+1}
\]

\[
\sum_{j=1}^{n} \lambda_{j} y_{ij} + \sum_{f=1}^{l} \pi_{f} q_{kf} \geq y_{k}^{t+1}
\]

\[
\lambda_{j} \geq 0
\]

\[
\pi_{f} \geq 0
\]

\[
y_{k}^{t+1} \geq 0
\]

So, the revenue efficiency for DMU\(_o\) in period \(t+1\) and frontier period \(t\) is:

\[
E_{R(t)}^{t+1(TO)} = \frac{\sum_{k=1}^{s} P_{ko} y_{k}^{t+1}}{\sum_{k=1}^{s} P_{ko} y_{k}^{t}}
\]  

(12)

Consider the following equations:

\[
REC = \frac{E_{R(t)}^{t+1(CRS)}}{E_{R(t)}^{t}}
\]  

(13)

\[
PREC = \frac{E_{R(t)}^{t+1(VRS)}}{E_{R(t)}^{t}}
\]  

(14)

\[
RTC = \left[ \frac{E_{R(t)}^{t+1(CRS)}}{E_{R(t)}^{t}} \right]^{\frac{1}{2}} \times \left[ \frac{E_{R(t)}^{t+1(VRS)}}{E_{R(t)}^{t+1}} \right]^{\frac{1}{2}}
\]  

(15)

\[
SREC = \left[ \frac{E_{R(t)}^{t+1(VRS)}}{E_{R(t)}^{t+1}} \right]^{\frac{1}{2}} \times \left[ \frac{E_{R(t)}^{t+1(CRS)}}{E_{R(t)}^{t}} \right]^{\frac{1}{2}}
\]  

(16)

Where REC is Revenue Efficiency Change, PREC is Pure Revenue Efficiency Change, RTC is Revenue Technology Change and SREC is Scale Revenue Efficiency Change. The malmquist index and its FGLR and FGNZ decompositions are as follows (for more details, see Fare et al., 1992, 1994). By similar way we can compute revenue malmquist

Revenue Malmquist Index (RMI) = REC × RTC

(17)

Revenue Malmquist Index (RMI) = PREC × SREC × RTC

(18)

We define:

\[
EREC = \frac{E_{R(t)}^{t+1(TO)}}{E_{R(t)}^{t}}
\]  

(19)

\[
ERTC = \left[ \frac{E_{R(t)}^{t+1(TO)}}{E_{R(t)}^{t+1}} \right]^{\frac{1}{2}} \times \left[ \frac{E_{R(t)}^{t+1(VRS)}}{E_{R(t)}^{t+1}} \right]^{\frac{1}{2}}
\]  

(20)

\[
RREC = \left[ \frac{E_{R(t)}^{t+1(TO)}}{E_{R(t)}^{t+1}} \right]^{\frac{1}{2}} \times \left[ \frac{E_{R(t)}^{t+1(CRS)}}{E_{R(t)}^{t}} \right]^{\frac{1}{2}}
\]  

(21)

Where EREC is Expanded Revenue Efficiency Change, ERTC is Expanded Revenue Technology Change and RREC is Regulation Revenue Efficiency Change. So

Expanded Revenue malmquist index (ERMI) = EREC×ERTC

(22)

or Expanded Revenue malmquist index(ERMI) = REC×ERMI×ERTC

(23)

By adding VRS technology, we have PREC and SREC. Therefore, we have another decomposition of the ERMI:

Expanded Revenue malmquist index (ERMI) = PREC×SREC×RREC×ERTC

(24)

if \(RMI_{j} > 1\) or \(ERMI_{j} > 1\), it shows DMU\(_j\) had progress.

If \(RMI_{j} < 1\) or \(ERMI_{j} < 1\), it shows DMU\(_j\) had regress.

If \(RMI_{j} = 1\) or \(ERMI_{j} = 1\), it shows DMU\(_j\) had not changes.

Centralized Decision Making Unit (CDMU)

Suppose there are \(n\) DMUs which have been defined as above. The VRS centralised DEA model is as follows:

\[
\theta^{*} = \min \theta
\]

s.t

\[
\sum_{k=1}^{s} \sum_{j=1}^{n} \lambda_{j} x_{ij} \leq \theta \sum_{k=1}^{s} x_{ik}
\]

\(i=1,2,\ldots,m\)
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\[ \sum_{r=1}^{n} \lambda_{rk} y_{rk} \geq \sum_{k=1}^{s} y_{rk} \quad r=1,2,\ldots,s \quad (25) \]
\[ \sum_{j=1}^{n} \lambda_{kj} = 1 \quad k=1,2,\ldots,n \]
\[ \lambda_{kj} \geq 0 \quad k,j=1,2,\ldots,n \]

\( \theta \) Free variable

For more details about C.DMU see Lozano and et al.(2009).
C.DMU is efficient if and only if \( \theta(VRS) = 1 \). Model (25) is equivalent Model (26).

\[ \theta(VRS) = \text{min} \theta \]
\[ \sum_{j=1}^{n} \sum_{k=1}^{s} \lambda_{kj} x_{ij} \leq \theta \sum_{k=1}^{s} x_{ik} \quad i=1,2,\ldots,m \quad (26) \]
\[ \sum_{j=1}^{n} \lambda_{kj} y_{j} \geq \sum_{k=1}^{s} y_{rk} \quad r=1,2,\ldots,s \]
\[ \sum_{j=1}^{n} \lambda_{kj} = 1 \quad k=1,2,\ldots,n \]
\[ \lambda_{kj} \geq 0 \quad k,j=1,2,\ldots,n \]

\( \theta \) free variable

The component of C.DMU is \( x_1, \ldots, x_m, y_1, \ldots, y_s \) that \( x_j = \sum_{i=1}^{n} x_{ij} \) for all \( i = 1, 2, \ldots, m \) and \( y_r = \sum_{j=1}^{n} y_{jr} \) for \( r = 1, 2, \ldots, s \). For evaluating efficiency of C.DMU in Trade offs model in DEA, consider model (27).

\[ \theta^*(TO) = \text{min} \theta \]
\[ \sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_{ij} x_{ij} + \sum_{j=1}^{n} \pi_{kj} y_{jr} \leq \theta \sum_{k=1}^{s} x_{ik} \quad i=1,2,\ldots,m \quad (27) \]
\[ \sum_{j=1}^{n} \sum_{k=1}^{s} \lambda_{kj} y_{j} \geq \sum_{r=1}^{n} y_{rk} \quad r=1,2,\ldots,s \]
\[ \sum_{j=1}^{n} \lambda_{kj} = 1 \quad k=1,2,\ldots,n \]
\[ \lambda_{kj} \geq 0 \quad k,j=1,2,\ldots,n \]
\[ \pi_{kj} \geq 0 \quad k=1,2,\ldots,n, \quad f=1,2,\ldots,l \]

\( \theta \) free variable

Revenue Efficiency for Centralized DMU
Assuming that are \( n \) DMUs each with \( m \) inputs and \( s \) outputs, we evaluate the revenue efficiency of C.DMU as follows:

\[ R^{(VRS)} = \text{Max} \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk} \]
\[ \text{S.t} \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} x_{ij} \leq \sum_{r=1}^{n} x_{ir} \quad i=1,2,\ldots,m \quad (28) \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} y_{j} \leq \sum_{r=1}^{n} y_{rk} \quad k=1,2,\ldots,s \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} = 1 \quad r=1,2,\ldots,n \]
\[ \lambda_{rj} \geq 0 \quad r,j=1,2,\ldots,n \]
\[ \pi_{rk} \geq 0 \quad k=1,2,\ldots,n \]

Where \( j \) is the DMU index \( j = 1, 2, \ldots, n \), \( k \) the output index, \( k = 1, 2, \ldots, s \) and \( i \) the input index \( i = 1, 2, \ldots, m \). \( y_{kj} \) the value of the kth output for the jth DMU, \( x_{ij} \) the value of the i the input for the jth DMU and \( p_{kr} \) the revenue of k output for the r = jth DMU.

The constraint \( \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk} \leq \sum_{r=1}^{n} p_{rk} y_{rk} \) ensure the revenue obtained from solving model (28) is more equal than revenue of previous. Therefore

\[ E^{(VRS)}_R = \frac{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}}{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}} \quad (29) \]

Revenue Malmquist Index for Centralised DMU In Different Models of DEA
We compute the revenue malmquist index for CDMU in different models of DEA (VRS, TO), (with having previous assumption).DEA model with VRS technology and input orientation

Frontier period=t, CDMU period=t

\[ R^{(VRS)}_t = \text{Max} \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \]
\[ \text{S.t} \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} x_{ij}^{(t)} \leq \sum_{r=1}^{n} x_{ir}^{(t)} \quad i=1,2,\ldots,m \quad (30) \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} y_{j}^{(t)} \leq \sum_{r=1}^{n} y_{rk}^{(t)} \quad k=1,2,\ldots,s \]
\[ \sum_{r=1}^{n} \sum_{j=1}^{s} \lambda_{rj} = 1 \quad r=1,2,\ldots,n \]
\[ \lambda_{rj} \geq 0 \quad r,j=1,2,\ldots,n \]
\[ y_{rk}^{(t)} \geq 0 \quad k=1,2,\ldots,n \]

Therefore, revenue efficiency for CDMU in period t and frontier period t is:

\[ E^{(VRS)}_{R(t)} = \frac{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}}{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}} \quad (31) \]
The computation of $R^{t+1}_{(VRS)}$ for C.DMU is like (30), where $t + 1$ is substituted for $t$. DEA model with VRS technology and input orientation

Frontier period=t, CDMU period=t + 1

$$R^{t+1}_{(VRS)} = \text{Max} \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

S.t

$$\sum_{i=1}^{n} x_{ir}^{t+1} \leq \sum_{r=1}^{n} \alpha_{r}^{t+1} y_{rk}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

Therefore, revenue efficiency for CDMU in period $t + 1$ and frontier period $t$ is:

$$E^{t+1}_{R(t)} = \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

DEA model with VRS technology and input orientation

Frontier period=t + 1, CDMU period=t

$$R^{t+1}_{(VRS)} = \text{Max} \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

S.t

$$\sum_{i=1}^{n} x_{ir}^{t+1} \leq \sum_{r=1}^{n} \alpha_{r}^{t+1} y_{rk}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

$$\sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1} \leq \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

Therefore, revenue efficiency for CDMU in period $t + 1$ and frontier period $t$ is:

$$E^{t+1}_{R(t)} = \sum_{r=1}^{n} \sum_{j=1}^{s} \sum_{k=1}^{p} y_{rk} x_{ij}^{t+1}$$

The cost malmquist index for CDMU (CMIC) based on VRS model in DEA is as follows:(for more details, see Fare and et.al(1992,1994))

$$RMC_{IC}^{(VRS)} = \frac{R^{t+1}_{(VRS)}}{R^{t}_{(VRS)}} \times \frac{E^{t+1}_{R(t)}}{E^{t}_{R(t)}}$$

Where $\frac{R^{t+1}_{(VRS)}}{R^{t}_{(VRS)}}$ is pure revenue efficiency change of CDMU and we show PRECC And $\frac{E^{t+1}_{R(t)}}{E^{t}_{R(t)}}$ is Revenue technology change of CDMU and we show RTCC, so:

$$\text{RMIC}_{IC}^{(VRS)} = \text{PRECC} \times \text{RTCC}$$

Suppose we have I Trade offs. We shall represent the Trade offs in form (Dif, Qkf) for i = 1, 2, ..., m, k = 1, 2, ..., s and f = 1, 2, ..., I(for more details about Trade offs model of DEA see Podinovski (2004)). DEA model with Trade off technology and input orientation

Frontier period=t, CDMU period=t
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\[ R_1^{(t+0)} = \text{Max} \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \]
S.t. 
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} x_{ij}^{(t)} + \sum_{j=1}^{s} \pi_{rj} d_{ij}^{(t)} \right) \leq \sum_{r=1}^{n} x_{ir}^{(t)} \quad i=1,2,\ldots,m \]
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} y_{jk}^{(t)} + \sum_{j=1}^{s} \pi_{rj} q_{jk}^{(t)} \right) \geq \sum_{r=1}^{n} y_{rk}^{(t)} \quad k=1,2,\ldots,s \]  
(38)
\[ \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \leq \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \]
\[ \sum_{j=1}^{s} \lambda_{ij} = 1 \quad r=1,2,\ldots,n \]
\[ \lambda_{ij} \geq 0 \quad r,j=1,2,\ldots,n \]
\[ \pi_{rj} \geq 0 \quad r=1,2,\ldots,n \quad f=1,2,\ldots,l \]
\[ y_{rk}^{(t)} \geq 0 \quad r=1,2,\ldots,n \quad k=1,2,\ldots,s \]

Hence, cost efficiency for CDMU in period t and frontier period t is:
\[ E_{R(t)}^{(t+0)} = \frac{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}}{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}} \]  
(39)

The computation of \( R_{+1}^{(t+1)} \) for CDMU is like (38), where t + 1 is substituted for t.

DEA model with Trade off technology and input orientation

Frontier period= t, CDMU period= t + 1
\[ R_{t+1}^{(t+0)} = \text{Min} \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t+1)} \]
S.t. 
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} x_{ij}^{(t+1)} + \sum_{j=1}^{s} \pi_{rj} d_{ij}^{(t+1)} \right) \leq \sum_{r=1}^{n} x_{ir}^{(t+1)} \quad i=1,2,\ldots,m \]
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} y_{jk}^{(t+1)} + \sum_{j=1}^{s} \pi_{rj} q_{jk}^{(t+1)} \right) \geq \sum_{r=1}^{n} y_{rk}^{(t+1)} \quad k=1,2,\ldots,s \]  
(40)
\[ \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t+1)} \leq \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t+1)} \]
\[ \sum_{j=1}^{s} \lambda_{ij} = 1 \quad r=1,2,\ldots,n \]
\[ \lambda_{ij} \geq 0 \quad r,j=1,2,\ldots,n \]
\[ \pi_{rj} \geq 0 \quad r=1,2,\ldots,n \quad f=1,2,\ldots,l \]
\[ y_{rk}^{(t+1)} \geq 0 \quad r=1,2,\ldots,n \quad k=1,2,\ldots,s \]

So, cost efficiency for CDMU in period t + 1 and frontier period t is:
\[ E_{R(t)}^{(t+1)} = \frac{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t+1)}}{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t+1)}} \]  
(41)

DEA model with Trade off technology and input orientation

Frontier period=t + 1, CDMU period=t
\[ R_{t+1}^{(t+1)} = \text{Min} \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \]
S.t. 
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} x_{ij}^{(t+1)} + \sum_{j=1}^{s} \pi_{rj} d_{ij}^{(t+1)} \right) \leq \sum_{r=1}^{n} x_{ir}^{(t+1)} \quad i=1,2,\ldots,m \]
\[ \sum_{r=1}^{n} \left( \sum_{j=1}^{s} \lambda_{ij} y_{jk}^{(t+1)} + \sum_{j=1}^{s} \pi_{rj} q_{jk}^{(t+1)} \right) \geq \sum_{r=1}^{n} y_{rk}^{(t+1)} \quad k=1,2,\ldots,s \]  
(42)
\[ \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \leq \sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)} \]
\[ \sum_{j=1}^{s} \lambda_{ij} = 1 \quad r=1,2,\ldots,n \]
\[ \lambda_{ij} \geq 0 \quad r,j=1,2,\ldots,n \]
\[ \pi_{rj} \geq 0 \quad r=1,2,\ldots,n \quad f=1,2,\ldots,l \]
\[ y_{rk}^{(t)} \geq 0 \quad r=1,2,\ldots,n \quad k=1,2,\ldots,s \]

Therefore, cost efficiency for C.DMU in period t + 1 and frontier period t is:
\[ E_{R(t)}^{(t+1)} = \frac{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}}{\sum_{r=1}^{n} \sum_{k=1}^{s} p_{rk} y_{rk}^{(t)}} \]  
(43)

The revenue expanded malmquist index for C.DMU (ERMIC) based on Trade off model in DEA is as follows:(for more details, see Fare and et.al(1992,1994))
\[ ERMIC^{(VRS)} = \frac{E_{R(t)}^{(t+1)}}{E_{R(t)}^{(t+0)}} \times \frac{E_{R(t)}^{(t+0)}}{E_{R(t)}^{(t+1)}} \times \frac{E_{R(t)}^{(t)}}{E_{R(t)}^{(t)}} \]  
(44)

Where \( E_{R(t)}^{(t+1)} \) is expanded revenue efficiency change of C.DMU and we show ERECC
And \( \left( \frac{\hat{e}_{r(t)}^{(r(t))}}{\hat{e}_{r(t)}^{(r(t))}} \times \frac{\hat{e}_{r(t+1)}^{(r(t+1))}}{\hat{e}_{r(t+1)}^{(r(t+1))}} \right)^{1/2} \) is expanded revenue technology change of C.DMU and we show ERTCC, so:

\[
ERMIC = ERECC \times ERTCC
\]

We define revenue malmquist index disparity

\[
CMID = \frac{RMI - ERMIC}{RMI} \times 100
\]

\[
ECMID = \frac{ERMI - ERMIC}{ERMI} \times 100
\]

**Example**

Consider Table (1)...(4) in this Tables, we have ten DMUs with three inputs and five outputs at two periods. Data have been taken from a commercial Bank in IRAN for ten branches. Assume that all DMUs agree as being true for the following judgements at two periods,(we have three trade offs in each period) and vector \( P \) is price of outputs.

1. \((P_1^t, Q_1^t) = (p_1^{t1}, p_1^{t2}, p_1^{t3}, q_1^{t1}, q_1^{t2}, q_1^{t3}, q_1^{t4}, q_1^{t5}) =
\)
\((-10,100000000,1000000000,10000000000,100000000000,1000000000000)

2. \((P_2^t, Q_2^t) = (p_2^{t1}, p_2^{t2}, p_2^{t3}, q_2^{t1}, q_2^{t2}, q_2^{t3}, q_2^{t4}, q_2^{t5}) =
\)
\((-15,20000000000,20000000000,111000000000,1000000000000,9000000000000)

3. \((P_3^t, Q_3^t) = (p_3^{t1}, p_3^{t2}, p_3^{t3}, q_3^{t1}, q_3^{t2}, q_3^{t3}, q_3^{t4}, q_3^{t5}) =
\)
\((-10,100000000,20000000000,100000000000,1200000000000,10000000000000, -30000000000)

4. \((P_1^{t+1}, Q_1^{t+1}) = (p_1^{t+1}, p_1^{t+1}, p_1^{t+1}, q_1^{t+1}, q_1^{t+1}, q_1^{t+1}, q_1^{t+1}, q_1^{t+1}) =
\)
\((-10,100000000,1000000000,100000000000,1000000000000,11000000000000,10000000000000)

5. \((P_2^{t+1}, Q_2^{t+1}) = (p_2^{t+1}, p_2^{t+1}, p_2^{t+1}, q_2^{t+1}, q_2^{t+1}, q_2^{t+1}, q_2^{t+1}, q_2^{t+1}) =
\)
\((-15,20000000000,20000000000,111000000000,1000000000000,9000000000000)

6. \((P_3^{t+1}, Q_3^{t+1}) = (p_3^{t+1}, p_3^{t+1}, p_3^{t+1}, q_3^{t+1}, q_3^{t+1}, q_3^{t+1}, q_3^{t+1}, q_3^{t+1}) =
\)
\((-10,100000000,20000000000,100000000000,1200000000000,100000000000000, -30000000000)

**Table 1:** Inputs in period t

<table>
<thead>
<tr>
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<th>( X_3 )</th>
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Table 2: Outputs in period t

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<td>DMU 4</td>
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Table 3: Inputs in period t+1

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Table 4: Outputs in period t+1

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Table 5: Price of Outputs in period t

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Table 6: price of Outputs in period t+1

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Table 7: Revenue Malmquist Index For ten DMUs.

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<th>SREC</th>
<th>RM I</th>
<th>ERT C</th>
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<th>REM I</th>
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Table 8: Revenue Malmquist Index in CRS model of DEA

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<thead>
<tr>
<th>Unit</th>
<th>$E_{R(t)}^+$</th>
<th>$E_{R(t+1)}^+$</th>
<th>$E_{R(t)}^{t+1}$</th>
<th>$E_{R(t+1)}^{t+1}$</th>
<th>P RECC</th>
<th>RT CC</th>
<th>RM IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.DM U</td>
<td>0.7342</td>
<td>0.7243</td>
<td>1.2673</td>
<td>0.6671</td>
<td>0.9865</td>
<td>0.7305</td>
<td>0.7206</td>
</tr>
</tbody>
</table>

Table 9: Revenue Malmquist Index in Trade offs model of DEA

<table>
<thead>
<tr>
<th>Unit</th>
<th>$E_{R(t)}^*$</th>
<th>$E_{R(t+1)}^*$</th>
<th>$E_{R(t)}^{t+1}$</th>
<th>$E_{R(t+1)}^{t+1}$</th>
<th>ERECC</th>
<th>ERTCC</th>
<th>ERM IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.DM U</td>
<td>0.2707</td>
<td>0.2650</td>
<td>0.2807</td>
<td>0.2555</td>
<td>0.9790</td>
<td>0.9643</td>
<td>0.9441</td>
</tr>
</tbody>
</table>

Conclusion

In this paper revenue efficiency for different models of DEA have been evaluated. The result shows that all of DMUs had regress. In case of using Trade off technologies the situations worsen. For CDMU the result shows very unsatisfactory situation.

References


