

# Efficiency Analysis of Electric Power Utilities of United States and Japan Using Data Envelopment Analysis

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**Abstract:** I have investigated an efficiency of electric power utilities of the United States and Japanese electric companies using data envelopment analysis. The analysis can be newly constructed with an effective graphical expression of the efficiency in a diagram of two-input one-output models. I show that it is very useful to graphically illustrate the assessment of efficiencies due to the analysis based on time series data with several examples and discussion.

Key Words: Data envelopment analysis, Electric power utilities of the United States, Practical comprehension

## 1. Introduction

Japan's earthquake gave Tsunami and nuclear crisis (11 March, 2011) as a nuclear power plant accident caused by the earthquake. In promoting energy conservation and efficient use of energy worldwide, in particular, an energy strategy has become very important for electric power management. As an assessment using the measure model for efficient activity of the industry, data envelopment analysis (DEA) is widely used due to a nonparametric data treatment [1]. Input and output data obtained from the activities are evaluated with the DEA efficiency that depends on each industry's activity. The analysis explicitly gives us the improvement points in the activity data. The DEA has been developed from CCR (Charnes, Cooper and Rhodes) analysis to BCC (Banker, Charnes, and Cooper) analysis [1]. Using them to measure the performance of decision making units (DMU) of the power industries, more precise assessments are carried out to the efficient use of energy in the electric power management.

The electric power companies in Japan are vertically integrated as structures of electricity business unlike those in Europe and the United States (US). Each company of Japan makes a monopoly-type business in the respective regions and also has several functions, such as generation, transmission, distribution and sales. Overall efficiency of the electric power managements has localized effects of the regions in comparison with Japanese power companies.

In this report, the US data is employed for the entire US power industry of EIA [2] and Japanese data of power industry as a whole entity are the data of

averaged 9 Japanese electric power companies [3] without Okinawa power company.

I have compared the efficiencies of electric power utilities of US and Japan power industries by DEA method. The efficient use of the power equipments is investigated by the results of CCR and BCC analyses with time series data from 1998 to 2009.

DEA technique measures a relative efficiency between business entities based on the data provided as a lot of plural input data elements and plural output products [4]. However, it is difficult to individually pick up the effect from many inputs and outputs. Therefore, 2-input 1-output data are adopted to maximize the efficiency for simplicity. The efficiency has to be evaluated by choosing the input and output data heuristically. When the optimal DEA assessment can be done, we can make an improvement clear by the difference between efficiency and inefficiency results in CCR and BCC analyses.

Here, I describe a brief outline of model (CCR and BCC analyses) of DEA and compare the energy-use efficiency of the electricity business industry using each DEA analysis by 2-input 1-output type expression with time series data. Especially I show that it is very useful to graphically illustrate the assessment of its efficiency due to our analysis with the time series data by several examples and discussion.

## 2. DEA method

I describe the DEA method briefly. There are two methods of CCR and BCC [1]. At first we can apply the theory of minimization of the LP (linear programming) method to the theory of CCR maximization about the mathematical procedure of the

CCR analysis of DEA method using the dual transformation [1]. That is;

$$\begin{aligned}
 & \text{[LP minimization]} \\
 & \min \quad \theta \\
 & \text{s.t.} \quad \theta \mathbf{x}_0 - \mathbf{X} \boldsymbol{\lambda} \geq \mathbf{0} \\
 & \quad \quad \mathbf{y}_0 - \mathbf{Y} \boldsymbol{\lambda} \leq \mathbf{0} \\
 & \quad \quad \boldsymbol{\lambda} \geq \mathbf{0} \quad \dots \dots (1)
 \end{aligned}$$

Here,  $x_0$  is each DMU's input data and  $y_0$  is output data.  $\theta$  is the objective function in the LP minimization operation of LP method.  $X$  and  $Y$  are virtual input and virtual output vectors, respectively.  $\lambda$  represents the weight vector of nonnegative values.

BCC model is developed to extend the CCR model to variable returns to scale. The eq. (1) of CCR is rewritten on the weight-vector  $\lambda$  of the LP algorithm, by adding the constraints  $\mathbf{e}^T \boldsymbol{\lambda} = \sum \lambda_j = 1$  as follows;

$$\begin{aligned}
 & \min \quad \theta \\
 & \text{s.t.} \quad \theta \mathbf{x}_0 - \mathbf{X} \boldsymbol{\lambda} \geq \mathbf{0} \\
 & \quad \quad \mathbf{y}_0 - \mathbf{Y} \boldsymbol{\lambda} \leq \mathbf{0} \\
 & \quad \quad \mathbf{e}^T \boldsymbol{\lambda} = 1, \quad \boldsymbol{\lambda} \geq \mathbf{0} \quad \dots \dots (2)
 \end{aligned}$$

The application examples are shown in the next section using these analyses.

### 3. Results of electric power industries

Here, DEA analysis is applied to measure efficient utility that shows inefficient and efficient DMU comparison of US and Japanese electricity industries. I describe the results using graphic illustration to the assessment of its efficiency due to the analysis with the time series data [8].

#### 3.1 The US electric power industry

DEA analysis of the electric power industry in the US is carried out by the previous reports [5, 6]. I show the recent analysis by the use of time-series data for the year 1998 up to 2009. Each DMU data is collected from the time series data of the annual indices [2]. The DMU data is shown in Fig. 1. The graph (a) is a bar graph which is displayed every year. The graph (b) is a radar chart of the graph (a) to compare each other in the later.

Input 1 is the ratio of operating expenses to total sales fee (%; O.E.: expense) and the input 2 is the electric energy loss (%; E.L.: energy loss) which is similar to the definition of Vaninsky in the reference [5]. The output is capacity utilization factor (%; C.U.: capacity

utilization) for the efficiency of the US electric power industry [5].

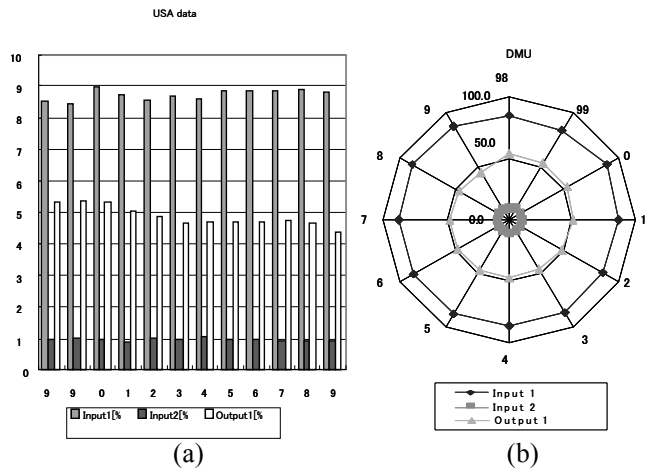


Fig. 1. (a) Actual DMU data from 1998 to 2009 of whole electric power industry in the United States. (b) Radar charts of (a).

The actual data are indicated for 12 years from 1998 to 2009. The energy loss every year seems small from the changes of actual data, but the loss power is a huge amount just across whole the electric power business. The electric energy we use is produced from the other primary energies of mechanical, chemical, thermal and nuclear energy etc. The electricity energy is very convenient for the use, but it gives rise to the energy loss due to the energy conversion, long distance transmission and distribution to industries and societies.

The efficiency consideration for electric energy use is very important in energy management. Using the above data, CCR and BCC efficiency analyses are carried out. Fig. 2 shows the results. The BCC results from 1998 to 2004 are coincident with those of Vaninsky [5].

The radar chart of Fig.2 (b) expresses the results in a compact area. We can immediately read the difference between CCR and BCC efficiency plots at the years from 1998 to 2009, because the time sequence is according to clock wise direction in a radar chart. The efficiency differences can be recognized as the distortion of a polygonal shape from a circle for a period from 2001 to 2009. The point of "1" shows the year 2001 for example. Also those of other years are similar to this expression. The radar chart emphasizes that the BCC efficiency is greater than the CCR efficiency by using the distortion of the shapes. The differences are investigated in detail using the slack analysis [7] with respect to the actual inputs and output.

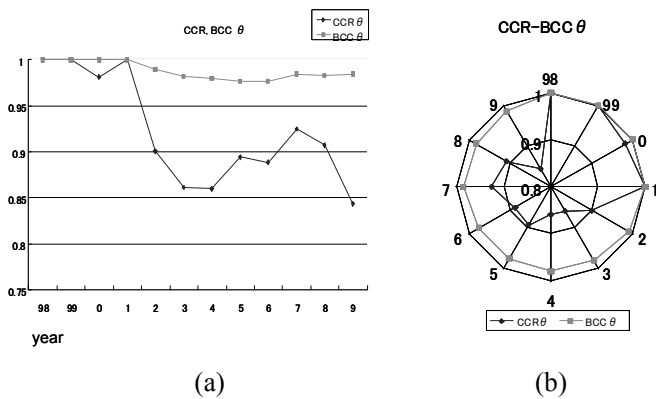


Fig.2. (a) is the results of CCR and BCC efficiency analyses and (b) shows the radar chart of result (a) for whole electric US industry.

Fig.3 shows the differences (i.e. slacks) between the virtual DMU ( $\theta=1.0$ ) and the actual DMU results of BCC and CCR, respectively. When the difference is zero, the DMU becomes efficient. The efficient DMU points are concentrated to the center of a circle.

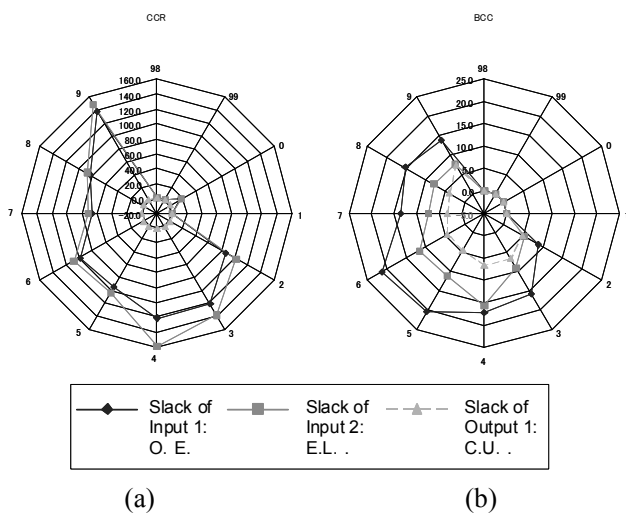


Fig.3. Radar charts of (a) CCR and (b) BCC inefficiency (slacks) analyses of US electric industries.

In the CCR result of Fig. 3(a) the slack points for both inputs 1 (expense) and 2 (energy loss) make the polygonal shapes, which inflate at the lower left for a period from 2002 to 2009. The respective slack points show the inefficiencies. Contrary to this shape, the CCR inefficiency curve of the above mentioned Fig. 2(b) shrinks to the circle center for the period. US has a lot of continuing economic crises corresponding to the period, such as the terrorist attacks in 2001,

bankruptcy of Enron, the attack on Iraq in 2003, a steep rise of oil prices from 2004 and the collapse of Lehman Brothers in 2008. The slacks of BCC analysis of Fig. 3(b) also indicate the similar result weakly. While they are numerically small. The result of the US is called as the Type 1.

### 3.2 Averaged Japanese power industry

Next, our analysis is applied to Japanese electric power industries to compare with the above US industries.

Japanese data of power industry as a whole entity are obtained from averaged 9 Japanese electric power companies [3] without Okinawa Power Company. The actual time series DMU data are shown in Fig. 4.

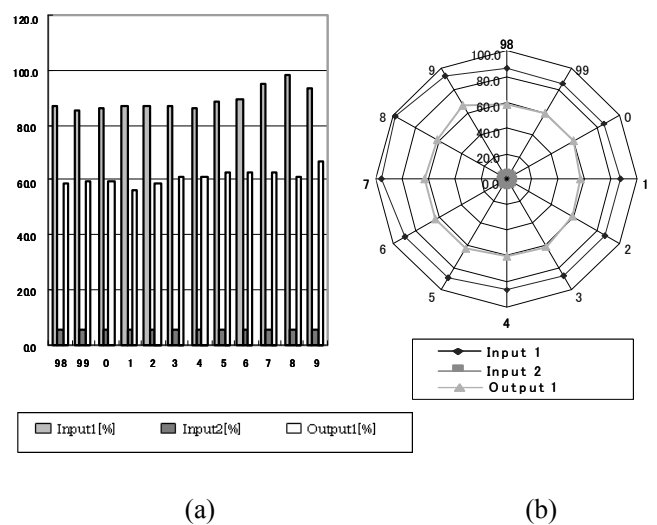


Fig. 4. (a) Time series DMU data averaged for 9 electric companies in Japan. (b) Radar charts of time series DMU data of (a).

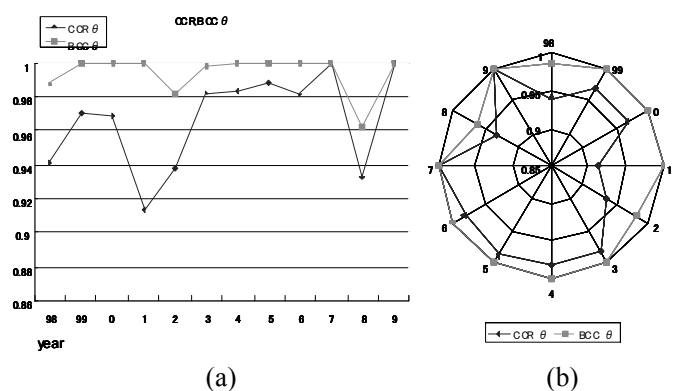


Fig. 5. (a) CCR and BCC efficiency results. (b) Radar charts of averaged 9 electric companies of Japan.

There is a big difference of the values between the input 1 (expense) and 2 (energy loss) data as shown in Fig. 4. In addition the annual change of those values is small, however the DEA calculation was carried out without hindrance.

The CCR and BCC efficiencies are shown in Fig. 5(a) and the radar charts (b), respectively. In contrast with above US results, the rapid recover appears in the CCR efficiencies of averaged Japan power industry, even after 2001 terrorist attacks or the collapse of Lehman Brothers (LB) in 2008 worldwide.

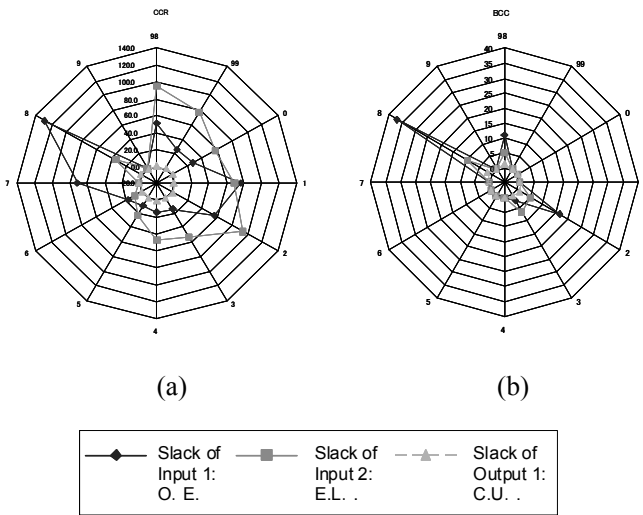


Fig.6. Radar charts of (a) CCR and (b) BCC inefficiency (slacks) analyses of averaged Japanese 9 electric companies.

Figure 6 shows the annual results using CCR and BCC analyses for the 9 averaged Japan industries. Fig. 6(a) and (b) show the radar charts of the CCR and BCC slacks, respectively. In the CCR slacks results of Fig. 6(a), the curve of input 2 (energy loss) is clearly separated from that of input 1 (expense). This implies that the operating expense has a trade-off relation with the energy loss in Japan.

In addition, the influence of Lehman shock of 2008 is remarkably seen for the BCC slack peak than the CCR slack peak. While the effective use of electricity is indicated in other years. The result of the averaged Japan is called as the Type 2.

### 3.3 Tokyo electric power company.

In order to compare with the US and averaged Japan power industries, further analyses are investigated for several major power companies in Japan.

First, we can see the case of Tokyo electric power company (TEPCO). Figure 7 shows the results of the

annual CCR and BCC efficiencies in (a) and the radar chart of (a) is shown in (b). The results are similar to those of the average Japan industry.

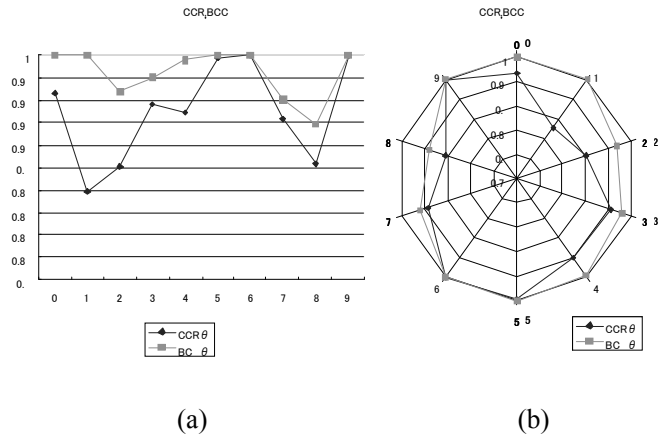


Fig. 7. The line graph (a) is the CCR and BCC results of TEPCO. The (b) shows the radar charts of (a).

Figure 8 indicates the radar charts of (a) CCR and (b) BCC slack analyses of TEPCO. In Fig. 8(a), the CCR slacks for the energy loss (input 2) have similar deviations to those for the operating expense (input 1) in the period from 2002 to 2004.

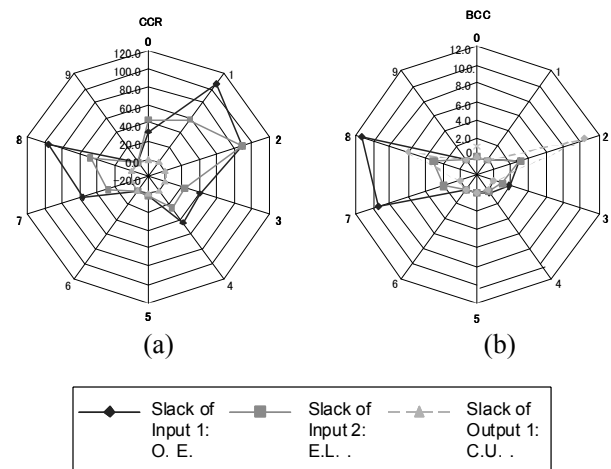


Fig.8. Radar charts of (a) CCR and (b) BCC inefficiency (slacks) analyses of TEPCO.

The former however is larger than the latter in the CCR result of Fig. 6(a) of averaged Japan industry. This means that the electric transmission and distribution network of TEPCO is well run over Kanto region than that of whole Japan. TEPCO suppresses the energy losses owing to the well developed power grid. In the BCC result of Fig. 8(b) the scale of

coordinates is multiplied by 10. Therefore the effects of the slacks are less than the CCR result of Fig. 8(a) by 10 times. The effect due to 2001 terrorist attacks or the collapse of Lehman Brothers (LB) in 2008 can however be seen remarkably. The result of TEPCO is called as the Type 3. Similar results are obtained for the Kansai electric power Co. (KEPCO) and Chubu electric power Co. (CEPCO), which are the major companies of Japan power industry. TEPCO, KEPCO and CEPCO supply 1/3, 1/6 and 1/6 of the whole Japanese electric power generation every year, respectively.

As we have seen, the above results of the three power companies make the most shape of that of the averaged 9 Japanese companies. However the slacks of energy losses are more prominent in the latter than the former. To see the difference in detail, let us investigate other local electric power companies of Japan in the following.

3.4 Kyushu electric power company.

The CCR and BCC efficiency results of Kyushu electric power company (Kyuden) resembles those of TEPCO, as shown in Fig. 9. However the recover at 2009 of LB shock in 2008 is weaker than that of TEPCO. Figure 10 shows the slack results by (a) CCR and (b) BCC analyses of Kyuden.

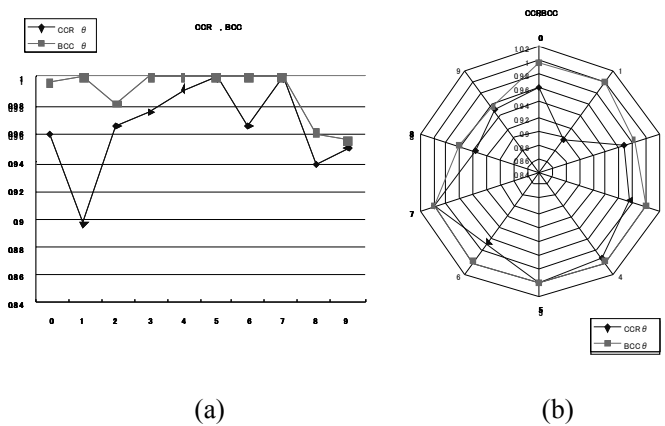


Fig. 9. (a) CCR and BCC efficiency results, and (b) the radar charts of Kyuden.

In the CCR result we can find that the slacks (inefficiencies) of input 2 (E.L.: energy losses) are beyond those of input 1 (O.E.: operating expense ratio) at the years from 2002 to 2004. We have ever seen the same feature in Fig. 6(a) of the averaged Japanese industry. This means that Kyuden has one of the significant influences to the CCR inefficiency result of the averaged Japanese power industry.

However the Japanese major 3 power companies do not show it clearly. Since Kyuden provides the electric power over the complex topographical area with a lot of islands, it seems that the energy losses considerably increase. The result of Kyuden is called as the Type 4.

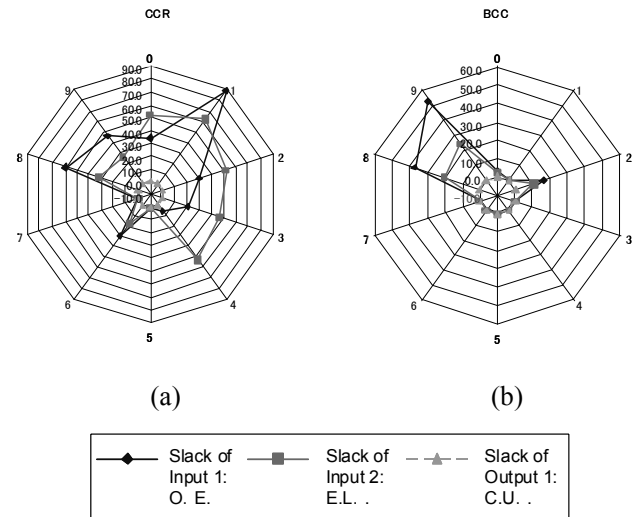


Fig.10. Radar charts of (a) CCR and (b) BCC inefficiency (slacks) analyses of Kyuden.

3.5 Chugoku electric power company.

Finally, I describe a different case of Chugoku electric power company (Chuden) among Japanese power companies. The business area of Chuden is located in the west Japan about 800 km distant from Tokyo. Figure 11 shows the results of CCR and BCC efficiency analyses.

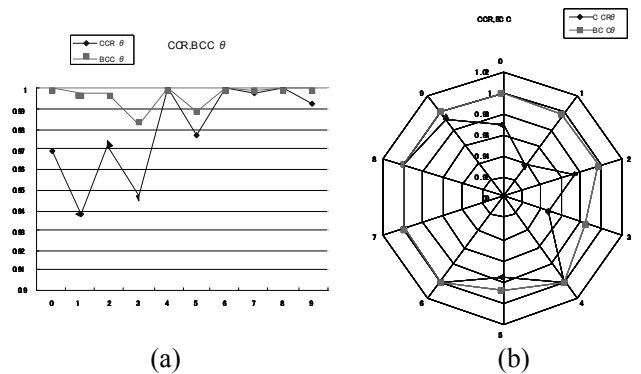


Fig.11. (a) CCR and BCC results and (b) the radar charts of Chuden.

The influence of Lehman shock at 2008 disappears and both of CCR and BCC results indicate that the efficiencies are efficient ( $\theta = 1.0$ ) from 2006 to 2008

in the graphs. The closed curve of the CCR efficiency is strongly biased to the left. This leads to the formation of polygons with bulges in the top right corner, as shown in CCR result of Fig. 12(a). The results of Fig. 12 are derived from the CCR and BCC slack analyses. Especially, as the BCC slack analysis has sharp peaks in Fig. 12(b), the efficiencies can be recovered in the short interval of year by year.

This reflects the business behavior of Chuden as a monopoly electric supplier and producer over the localized small service area. The result of Chuden is called as the Type 5.

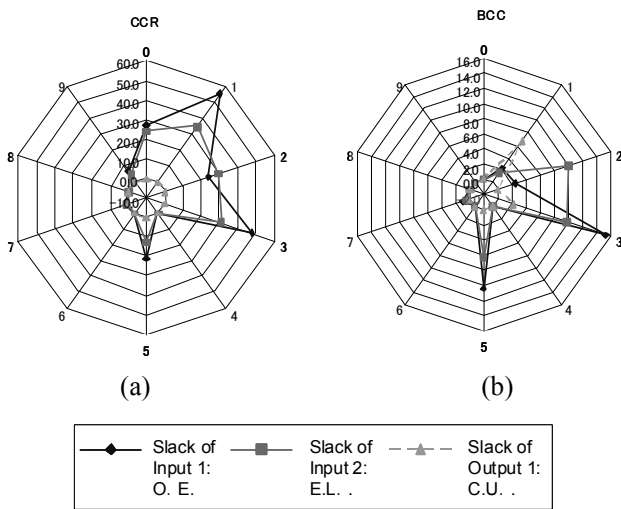


Fig.12. Radar charts of (a) CCR and (b) BCC inefficiency (slacks) of Chuden.

DEA analyses have been carried out about the power industries in Japan and the US during recent one decade. The respective analyses based on radar chart scheme are able to pick up the practical business features of power industries, which show the effective use of electric energy with the above examples. In measuring the DEA efficiency of power industries, I used the 2-input 1-output diagrams using time series data. The radar chart depends on how to choose the data. However, when we select suitable data sets, useful results can be easily obtained from the clear features of radar charts.

#### 4. Conclusion

I show a new analysis and expression of DEA method to support improvement to practical efficiencies of the US and Japanese power industries. A comparison of the results can be summarized as follows: First, it is very useful to distinguish CCR and BCC efficiencies which can be visually recognized with feature shapes

of radar charts. Second, the improvement points are directly indicated by DEA slack analysis on the radar charts with 2-input 1-output diagrams using time series data. Third, it is easy to classify the practical business behaviors of power industries with both of efficiency and slack analyses owing to the respective radar chart features. Therefore I can propose the practical analysis as a new powerful tool for DEA methods.

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