GRIPS Research Report Series I-2004-0004

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By

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First version: November 24, 2004

Research supported by Grant-in-Aid for Scientific Research(C)
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NATIONAL GRADUATE INSTITUTE
FOR POLICY STUDIES

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Abstract

This paper presents a new formula for decomposing cost efficiency into technical, price, and allocative efficiencies in an environment marked by the fact that unit input prices differ among certain enterprises. We employed this formula for comparing cost efficiency between Japan-US electric power companies and found a significant difference in the price-based efficiency between the two countries; however, negligible differences were found in the technical and allocative efficiencies.

Keywords: cost efficiency, technical efficiency, price efficiency, allocative efficiency, DEA.

1 Introduction

Technology and cost are the wheels that drive modern enterprises; some enterprises have advantages in terms of technology and others in cost. Hence, the management is eager to know how and to what extent their resources are being effectively and efficiently utilized, compared to other similar enterprises in the same or a similar field. Under multiple input-output correspondences, data envelopment analysis (DEA) has created a new route map for this purpose.

Given the quantities of input resources and output products, the representative DEA models, e.g., the CCR (Charnes *et al.*. (1978)), BCC (Banker *et al.*. (1984)), and SBM (Tone (2001)), can evaluate the relative technical efficiency of a given enterprise,

[1] Research supported by Grant-in-Aid for Scientific Research (C), Japan Society for Promotion of Science.

termed DMU (Decision Making Unit) in the DEA terminology. Furthermore, if the unit prices of the input resources are known, the cost efficiency model can be utilized to explore the optimal input-mix that produces the observed outputs at a minimum cost. Based on this optimal solution, the cost and allocative efficiencies are obtained. For example, see Farrell (1957) and Färe *et al.* (1985).

However, these traditional cost and allocative efficiencies, which assume the given uniform input prices, suffer from a critical shortcoming if the unit prices of the inputs are not identical among DMUs in the actual economy, as pointed out by Tone (2002). To cite a case, if two DMUs have the same amount of inputs and outputs and the unit price for one DMU is twice that of the other, then the traditional cost efficiency model assigns the same cost efficiency to both the DMUs. This appears rather strange and impractical in analyzing an actual economic situation. After indicating this shortcoming, Tone proposed a new scheme that is free from such inconsistencies.

This paper can be positioned as an extension of Tone (2002). We try to decompose the observed actual total cost into the global optimal (minimum) cost and loss due to input inefficiency as follows:

$$\text{Actual Cost} = \text{Minimum Cost} + \text{Loss due to Input Inefficiency}\,.$$

Furthermore, we represent this loss due to input inefficiency to be dependent on technical inefficiency, input price differences, and inefficient cost mix as follows:

$$\text{Loss due to Input Inefficiency} = \text{Loss due to Technical Inefficiency}$$

$$+ \text{Loss due to Input Price Difference} + \text{Loss due to Inefficient Cost Mix.}$$

Among them, technical efficiency is measured using the traditional CCR model within the supposed technical production possibility set. Then, using the obtained optimal input value, we construct a cost-based production possibility set and solve the New Tech and New Cost models on this set. This enables us to obtain two efficiency indices, i.e., the price efficiency index and the global allocative efficiency index. The former reflects an efficiency index regarding the differences in input unit prices, while the latter evaluates the efficiency of the input cost mix.

The remainder of the paper unfolds as follows. In the next section, we develop our methodology. We then apply our scheme to electric power industries in Japan and the US and compare the efficiencies of their performance from 1992 to 1999 in Section 3. It is often considered that the price of electricity in Japan is comparatively higher than that in other countries; this may be due to productive inefficiency or higher input prices. Certain prior studies have indicated that the productive efficiency of Japanese electric power companies was higher than that of their US counterparts[2]. It has also been mentioned that input prices in Japan are higher than those in the US. However, there exist few studies that have comprehensively examined the influence of productive inefficiency and higher input prices over the total cost. This study will analyze and demonstrate the degree of losses caused by technical inefficiency, input price differences, and suboptimal cost mix between Japan-US electric power companies. In Section 4, we develop some extensions of this model, and we summarize the results and conclude the paper in the final section.

2 Methodology

In this section we develop our scheme and discuss its rationality.

[2] Goto and Tsutsui (1998) and Hattori (2002).

2.1 Data

Throughout this paper, we consider n DMUs, each having m inputs for producing s outputs. For each DMU$_o$ ($o = 1,\cdots,n$), we denote the input and output vectors by $x_o \in R^m$ and $y_o \in R^s$, respectively. The input and output matrices are defined as $X = (x_1,\cdots,x_n) \in R^{m\times n}$ and $Y = (y_1,\cdots,y_n) \in R^{s\times n}$, respectively. We assume that $X > 0$ and $Y > 0$. For each DMU$_o$ ($o = 1,\cdots,n$), the input factor price vector for input x_o is denoted by $w_o \in R^m$ and the input factor price matrix is defined as $W = (w_1,\cdots,w_n) \in R^{m\times n}$. For DMU$_o$, the actual total input cost C_o is calculated as follows:

$$C_o = \sum_{i=1}^{m} w_{io} x_{io} \,. \tag{1}$$

We assume that the elements $w_{1o}x_{1o},\cdots,w_{mo}x_{mo}$ are denominated in homogenous units, viz., dollars, in order that the summation is significant.

2.2 Technical Efficiency

The production possibility set P is defined as

$$P = \{(x,y) \mid x \ge X\lambda,\ \ y \le Y\lambda,\ \ \lambda \ge 0\}. \tag{2}$$

The *technical efficiency* θ^* of DMU$_o$ is measured using the traditional input-oriented CCR Model:

$$\begin{aligned} &[\text{CCR}] \quad \theta^* = \min \theta \\ &\text{subject to } \theta x_o = X\lambda + s^- \\ &\qquad\qquad y_o = Y\lambda - s^+ \\ &\qquad\qquad \lambda \ge 0, s^- \ge 0, s^+ \ge 0. \end{aligned} \tag{3}$$

Let $(\theta^*, \lambda^*, s^{-*}, s^{+*})$ be an optimal solution for [CCR]. In solving [CCR], we employ the two-phase approach. First, we obtain θ^* by solving [CCR], and then, by fixing θ

at θ^*, we minimize the objective function $\sum_{i=1}^{m} s_i^- / x_{io} + \sum_{r=1}^{s} s_r^+ / y_{ro}$ subject to the [CCR] constraint. The projection to the efficient frontier is then given by[3]

$$[CCR-projection] \quad x_o^* = \theta^* x_o - s^{-*}, \ \ y_o^* = y_o + s^{+*}, \tag{4}$$

where x_o^* indicates the amount of technical efficient inputs for DMU$_o$ for producing y_o in that it is projected onto the strongly efficient portion of the production possibility set P.

The corresponding technically efficient total input cost for DMU$_o$ is calculated as

$$C_o^* = \sum_{i=1}^{m} w_{io} x_{io}^* = \sum_{i=1}^{m} w_{io} (\theta^* x_{io} - s^{-*}) \le \theta^* \sum_{i=1}^{m} w_{io} x_{io} = \theta^* C_o \le C_o. \tag{5}$$

The loss in input cost due to this technical inefficiency is expressed as follows:

$$L_o^* = C_o - C_o^* (\ge 0). \tag{6}$$

2.3 Price Efficiency

(x_o^*, y_o) is the production pair in the production possibility set P, and its input cost $w_o x_o^*$ cannot be reduced further by radially reducing the input x_o^*. However, taking into account the differences in input prices under the situation that the unit prices might differ from DMU to DMU, the cost can be reduced by reducing the input factor prices.

In order to determine the minimum cost, we observe the cost-based production possibility set P_c on the basis of Tone (2002) as follows:

$$P_c = \{(\bar{x}, y) \mid \bar{x} \ge \bar{X}\mu, \ \ y \le Y\mu, \ \ \mu \ge 0\}, \tag{7}$$

[3] When we do not employ slacks in the CCR-projection, we cannot evaluate the excess inefficient input for a part of the input factors. In this paper, we employ the CCR-projection including slacks in order to accurately identify the factor-oriented inefficiency.

where $\overline{X} = (\overline{x}_1, \cdots, \overline{x}_n) \in R^{m \times n}$, $\overline{x}_o = (\overline{x}_{1o}, \cdots, \overline{x}_{mo})$, and $\overline{x}_{io} = w_{io} x^*_{io}$. It should be noted that x^*_o represents the technically efficient input for producing y_o. Hence, we utilize $w_{io} x^*_{io}$ instead of $w_{io} x_{io}$ in order to eliminate the technical inefficiency to the maximum extent possible. Then, we solve the CCR model on P_c in a similar manner as that of [NTec] in Tone (2002), which is as follows:

$$\begin{aligned} &[\text{NTec}] \quad && \rho^* = \min \rho \\ &\text{subject to} && \rho \overline{x}_o = \overline{X} \mu + t^- \\ & && y_o = Y \mu - t^+ \\ & && \mu \geq 0, \ t^- \geq 0, \text{ and } t^+ \geq 0. \end{aligned} \tag{8}$$

Let $(\rho^*, \mu^*, t^{-*}, t^{+*})$ be an optimal solution for [NTec]. Then, $\rho^* \overline{x}_o = (\rho^* w_{1o} x^*_{1o}, \ldots, \rho^* w_{mo} x^*_{mo})$ indicates the radially reduced input vector on the (weakly) efficient frontier of the cost-based production set P_c. Hence, $\rho^* w_o = (\rho^* w_{1o}, \ldots, \rho^* w_{mo})$, assuming w^*_o, is the radially reduced input factor price vector for the technically efficient input x^*_o that can produce y_o.

In traditional economic theories, it is assumed that, in the market, the input factor price is determined to be a single market price under perfect competition, and this is treated as a given condition. However, the actual market does not necessarily function under perfect competition and differences in input factor prices are not uncommon. In comparison, higher factor prices have an impact on the total cost of DMUs as well as the productive inefficiency. We therefore focus on the level of input factor prices, and ρ^* might indicate the radial difference in the observed input price as compared to the minimum input price in the same cost mix. In this study, the input price difference is labeled as *price efficiency*[4].

The [NTec] projection is given by

$$[NTec-projection]\ \ \bar{x}_o^* = \rho^*\bar{x}_o - t^{-*},\ \ y_o^* = y_o + t^{+*}. \tag{9}$$

We define the radial efficient cost C_o^{**}, which is the technical and price efficient cost, and the loss L_o^{**} due to the difference of the input price as follows:

$$C_o^{**} = \sum_{i=1}^m \bar{x}_{io}^* = \sum_{i=1}^m (\rho^*\bar{x}_{io} - t^{-*}) \le \rho^* \sum_{i=1}^m \bar{x}_{io} = \rho^* C_o^* \le C_o^* \tag{10}$$

$$L_o^{**} = C_o^* - C_o^{**} (\ge 0). \tag{11}$$

2.4 Allocative Efficiency

Furthermore, we solve the [NCost] model on P_c as follows:

$$\begin{aligned} &[\text{NCost}] \quad C^{***} = \min e\bar{x} \\ &\text{subject to} \quad e\bar{x} \ge e\bar{X}\mu \\ &\qquad y_o \le Y\mu \\ &\qquad \mu \ge 0, \end{aligned} \tag{12}$$

where $e \in R^m$ is a row vector in which each element is equal to 1. Let $(\bar{x}_o^{**}, \mu^*)$ be an optimal solution. Then, the cost-based pair $(\bar{x}_o^{**}, y_o)$ is the cost minimum production in the supposed production possibility set P_c, which substantially differs from P if the unit prices of the inputs vary from DMU to DMU. The (global) allocative efficiency α^* of DMU$_o$ is defined as follows:

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[4] Farrell (1957) termed (local) allocative efficiency as "price efficiency," which is a notion different from that used in this paper. Färe and Grosskopf (1988) and Färe *et al.*. (1990, 1994) focused on "price space" which is the dual of input space and indicated price efficiency on price space, similar to technical and cost efficiency on input space, in order to identify shadow prices and calculate losses due to market imperfection. Price efficiency in this paper is similar to "Dual Technical Efficiency" or "Input Price Measure of Technical Efficiency" in Färe *et al.*. (1990, 1994). As compared to these studies, we tried to indicate technical and price inefficiency and the new allocative inefficiency on the same axis of input cost, as described in Section 2.5.

$$\alpha^{*} = \frac{C_o^{***}}{C_o^{**}} (\leq 1). \tag{13}$$

In comparison to the traditional (local) allocative efficiency, which indicates the adjustment to the optimal input mixture based on the given input price ratio, α^* represents the adjustment to the optimal cost mix, viz., the combination of the optimal input amount and input price mixture[5]. We also define the loss L_o^{***} due to the suboptimal cost mix as

$$L_o^{***} = C_o^{**} - C_o^{***} (\geq 0). \tag{14}$$

2.5 Decomposition of the Actual Cost

According to Eqs. (6), (11), and (14), we can naturally arrive at the following theorem.

[Theorem 1]

$$C_o \geq C_o^{*} \geq C_o^{**} \geq C_o^{***} \tag{15}$$

Furthermore, we can obtain the relationship among the optimal cost and losses, and the actual cost (C_o) can be decomposed into three losses and the minimum cost (C_o^{***}):

$$\begin{aligned} &L_o^{*} = C_o - C_o^{*} (\geq 0) \quad \text{Loss due to Technical inefficiency} \\ &L_o^{**} = C_o^{*} - C_o^{**} (\geq 0) \quad \text{Loss due to Price inefficiency} \\ &L_o^{***} = C_o^{**} - C_o^{***} (\geq 0) \quad \text{Loss due to Allocative inefficiency} \\ &C_o = L_o^{*} + C_o^{*} = L_o^{*} + L_o^{**} + C_o^{**} = L_o^{*} + L_o^{**} + L_o^{***} + C_o^{***}. \end{aligned} \tag{16}$$

The ratios of these costs explain the respective efficiencies, and the minimum cost can be decomposed into the following indices:

[5] The traditional Cost model is solved under the given input price ratio (the slope of the isocost line) because the cost function is homogeneous of degree +1 in input prices. In contrast, the New Cost model has no restriction on input prices. In this case, the optimal solution will be determined based on the activity in P_c that employs the most inexpensive total cost. The optimal cost mix expressed by the global allocative efficiency is the cost mix of this activity.

$$E_o = \frac{C_o^*}{C_o} (\le 1) \quad \text{Technical Efficiency (TE)}$$

$$E_o^* = \frac{C_o^{**}}{C_o^*} (\le 1) \quad \text{Price Efficiency (PE)}$$

$$E_o^{**} = \frac{C_o^{***}}{C_o^{**}} (\le 1) \quad \text{(Global) Allocative Efficiency (AE)} \tag{17}$$

$$C_o^{***} = C_o^{**} \times E_o^{**} = C_o^* \times E_o^* \times E_o^{**} = C_o \times E_o \times E_o^* \times E_o^{**}$$

$$\frac{C_o^{***}}{C_o} = E_o \times E_o^* \times E_o^{**} \quad \text{(Decomposition of total cost efficiency into TE, PE, and AE).}$$

Furthermore, we establish an identity that connects the total cost efficiency with the three loss ratios in the additive form.

$$1 = L_o^* / C_o + L_o^{**} / C_o + L_o^{***} / C_o + C_o^{***} / C_o . \tag{18}$$

If the DMU$_o$ is fully efficient, i.e., $C_o = C_o^{***}$, then the Technical, Price, and Allocative losses are zero; whereas, if it is inefficient ($C_o > C_o^{***}$), we can attribute the inefficiency to the three losses. If L_o^* / C_o dominates the others, the inefficiency of the DMU is primarily caused by technical inefficiency. On the other hand, if L_o^{**} / C_o dominates the others, it is judged that the inefficiency results from the comparatively higher input factor prices of the DMU. In case of L_o^{***} / C_o dominating the others, the inefficiency of the DMU results from the suboptimal input cost mix.

3 An Empirical Study

We apply this combined model for comparing the electric power companies in Japan with those in the US.

3.1 Background

It has been pointed out that the electric power price in Japan is comparatively higher than those of the other developed countries; this might be caused by the inefficiency of Japanese electric power companies. On the other hand, certain prior studies indicated that the productive efficiency of Japanese electric power companies was higher than their US counterparts, and the difference in electricity prices between Japan and the US must be due to other factors, such as the differences in input factor prices.

However, traditional DEA models did not take the differences in the input factor prices into consideration, which are assumed to be exogenously determined. Using the New Cost model and applying the optimal value of the CCR model, as mentioned in the previous section, the differences in input factor prices can be clearly considered, and we can decompose the total loss into the losses due to technical inefficiency, the differences in input price levels, and the suboptimal cost mix.

Using this combined model, this study attempts to compare the factors of losses of the total supply costs between Japan and the US and to search for the reason for higher electric power prices in Japan.

3.2 Japan-US Data

For DMUs, we consider 19 vertical-integrated electric power companies (9 Japanese and 10 US) from 1992 to 1999. There are 10 integrated electric power companies in Japan; however, this study excludes one of them—Okinawa Electric Power Company—because it is very small and only services customers in the Okinawa islands. We selected US companies that are equivalent to the Japanese companies with respect to factors such as scale of electric power sales, possession of nuclear power plant, etc. Table 1 lists the sample companies considered in this study.

Tab. 1: Japan-US Companies

Japan		US	
1	Hokkaido Electric Power Co.	10	AmerenUE
2	Tohoku Electric Power Co.	11	Arizona Public Service Co.
3	Tokyo Electric Power Co.	12	Baltimore Gas & Electric Co.
4	Chubu Electric Power Co.	13	Carolina Power & Light Co.
5	Hokuriku Electric Power Co.	14	Duke Energy Corp.
6	Kansai Electric Power Co.	15	Florida Power & Light Co.
7	Chugoku Electric Power Co.	16	Niagara Mohawk Power Corp.
8	Shikoku Electric Power Co.	17	PPL Electric Utilities Corp.
9	Kyusyu Electric Power Co.	18	Public Service Electric & Gas Co.
		19	Virginia Electric & Power Co.

Vertical-integrated companies perform several functions, such as generation, transmission, distribution, and so on, within the company itself. However, this study used overall data from the companies since the focus is on the total management performance of these companies. The input and output datasets are as follows:

Input 1	Capital data (Divisia Index)
Input 2	Labor data (Number of employees)
Input 3	Fuel data (BTU)
Cost 1	Total capital cost
Cost 2	Total labor cost
Cost 3	Total fuel cost
Output 1	Net electricity power sales

For capital data (Input 1), we use an integrated index of the representative capital asset of each function. We adopt a divisia index constructed on the basis of the following four factors: generation capacity (MW), transmission line length (km), distribution transformer capacity (VA), and index of capital stock for the general administrative division. The cost data corresponding to Input 1 (Cost 1) is the total cost for the capital input, which is the total sum of the maintenance and depreciation expenses.

The labor data (Input 2) is the total number of employees and the corresponding cost

(Cost 2) is the total amount of salaries and wages. In this case, we do not take the outsourcing cost into account because of the unavailability of data.

The fuel data is only related to the generation division; however, it would be an important factor because the fuel cost share is comparatively high (Figure 1). Since the fuel consumption units differ among gas, coal, and petroleum, they are converted into the common British Thermal Unit (BTU) in order to summate the quantity of fossil fuel data. Compared to fossil fuels, the heat quantity of the consumed nuclear fuel is difficult to measure. In this case, we perform backward calculations with the amount of nuclear power generation. assuming the thermal efficiency to be 0.35. The corresponding cost (Cost 3) is the total fuel cost including the fossil and nuclear fuels.

Furthermore, we obtained the input factor prices as the ratio: cost to input, e.g., (Cost 1)/(Input 1).

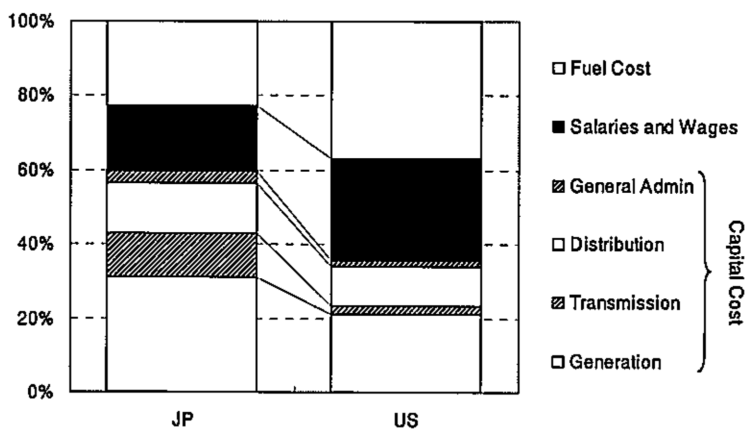


Fig. 1: Summary of Cost Structure

Concerning the cost data, Japanese yen is converted into dollars using Purchasing Power Parities (PPP) and all cost data are realized by Producer Prices Index of the US.

On the basis of these inputs, we assume that electric power companies produce net electric power sales[6]; which is excluded the power purchased from other companies.

The Japanese dataset is obtained from "Handbook of Electric Power Industry," published by the Federation of Electric Power Companies (FEPC) in Japan, and the US dataset is obtained from the "FERC FORM 1" disclosed by the Federal Energy Regulatory Commission (FERC). The major statistics of the datasets are described in Table 2.

Tab. 2: Major Statistics of Datasets from 1992 to 1999 (average)

	Japan					US				
	Av.	S.D.	Max	Min	Per net elec. sales (TWh)	Av.	S.D.	Max	Min	Per net elec. sales (TWh)
Capital (Divisia Index)	1.766	1.262	4.684	0.417	0.0247	1.089	0.483	2.065	0.418	0.0283
Generation (GW)	19,486	15,845	57,846	4,451	273	10,550	4,658	20,012	1,869	274
Transmission (km)	9,833	5,035	20,724	3,016	138	7,423	4,381	15,010	1,073	193
Distribution (VA)	29,594	24,211	86,149	5,177	414	20,703	9,518	42,656	10,557	538
General Admin (Index)	181,350	94,257	377,628	44,101	2,538	75,180	45,718	168,371	19,948	1,952
Employees (#)	15,831	10,738	41,067	5,060	222	8,421	3,034	17,666	3,978	219
Fule (10^9BTU)	673,686	614,639	2,289,134	97,458	9,427	394,248	169,817	780,175	115,970	10,236
Net elec. power sales (GWh)	71,461	62,576	231,797	12,486	-	38,515	17,690	77,778	12,859	-
Total Capital Cost*	2,995	2,517	9,716	554	42	469	185	1,153	249	12
Generation Division	1,517	1,210	4,690	281	21	280	123	732	135	7
Transmission Division	655	661	2,667	98	9	29	15	62	10	1
Distribution Division	694	609	2,320	130	10	139	57	326	57	4
General Admin Division	129	70	285	36	2	21	11	50	9	1
Salaries and Wages	824	593	2,331	229	12	355	137	685	171	9
Fuel Cost	1,176	1,041	4,300	156	16	513	290	1,383	166	13

The unit of cost data is million USD (1995 price).
* Japanese Total Capital Cost includes other miscellaneous capital costs.

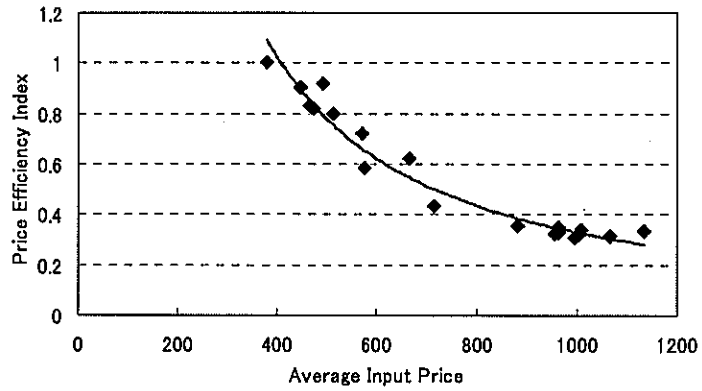
3.3 Empirical Result

(1) Verification of the performance of the Price Efficiency Index

First, we verify whether the price efficiency index introduced in this study corresponds well to the level of input factor prices. Figure 2 shows the price efficiency index in 1999. In this figure, the vertical axis indicates the measured price efficiency index and horizontal axis indicates the average factor price. According to our analytical

[6] We also considered the number of customers as an output. However, the scale between the two countries is completely different, and we decided it was inappropriate to employ the number of customers as an output.

framework, the price efficiency index should decrease with the rise in input factor prices.



*The curved line passing through the dots indicates an approximation.

Fig. 2: Comparison of Price Efficiency Index and Input Factor Prices (1999)

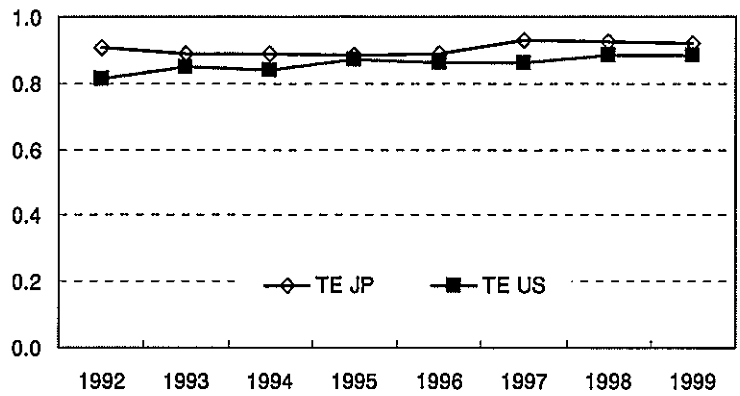
In effect, the price efficiency index is plotted in decreasing order. It is clearly seen that the higher the input prices, the smaller the index; we can say that the price efficiency index expresses the level of input factor prices well.

(2) Decomposition of Efficiency Indices

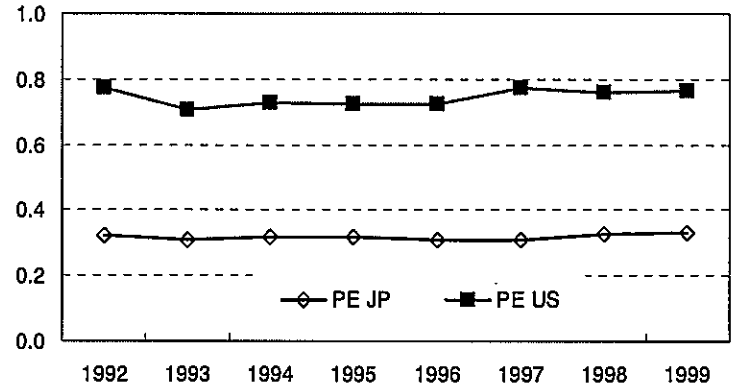
Table 3 and Figure 3 explain the results of Technical efficiency (E_o), Price efficiency (E_o^*), and Allocative efficiency (E_o^{**}) for Japanese and US DMUs on average.

Tab. 3: Results of the Efficiency Indices

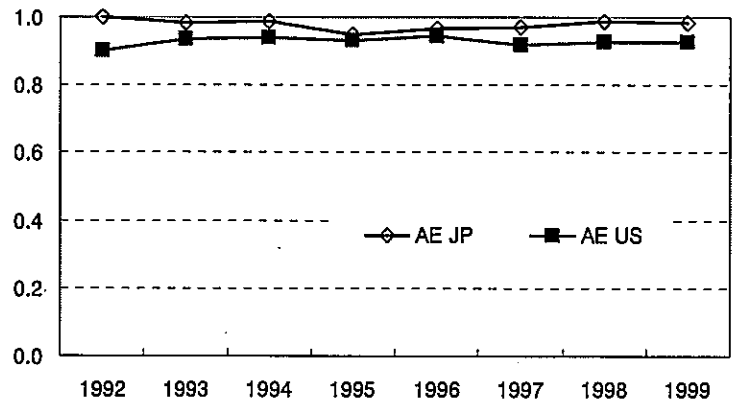
	1992	1993	1994	1995	1996	1997	1998	1999
Technical Efficiency								
JP Ave	0.906	0.887	0.889	0.882	0.890	0.929	0.923	0.921
US Ave	0.811	0.847	0.841	0.869	0.861	0.863	0.884	0.883
Price Efficiency								
JP Ave	0.320	0.309	0.316	0.315	0.306	0.308	0.324	0.330
US Ave	0.772	0.705	0.729	0.721	0.722	0.773	0.757	0.763
Global Allocative Efficiency								
JP Ave	1.000	0.985	0.988	0.949	0.964	0.971	0.987	0.982
US Ave	0.899	0.934	0.941	0.931	0.945	0.918	0.925	0.925



a. Technical Efficiency



b. Price Efficiency

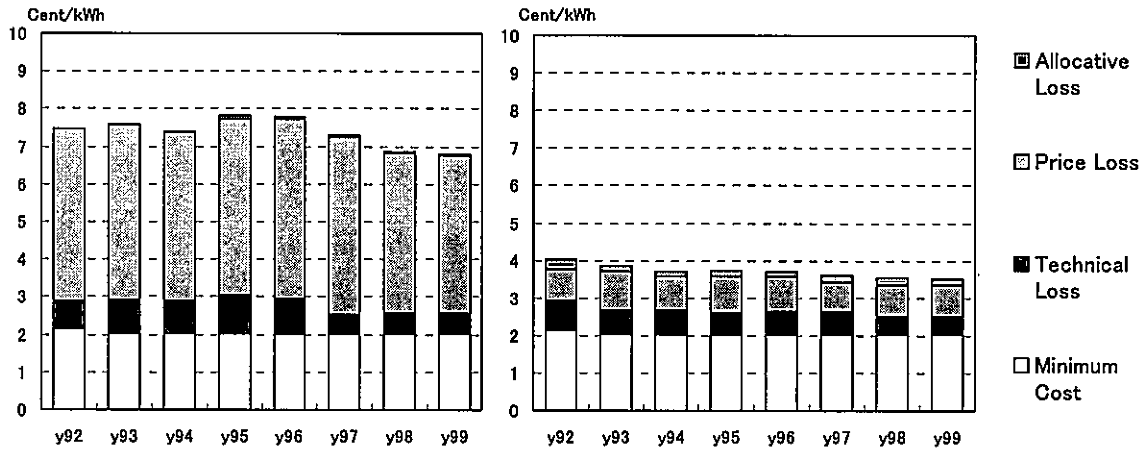


c. Allocative Efficiency

Fig. 3: The Results of the Efficiency Indices of JP and the US on average

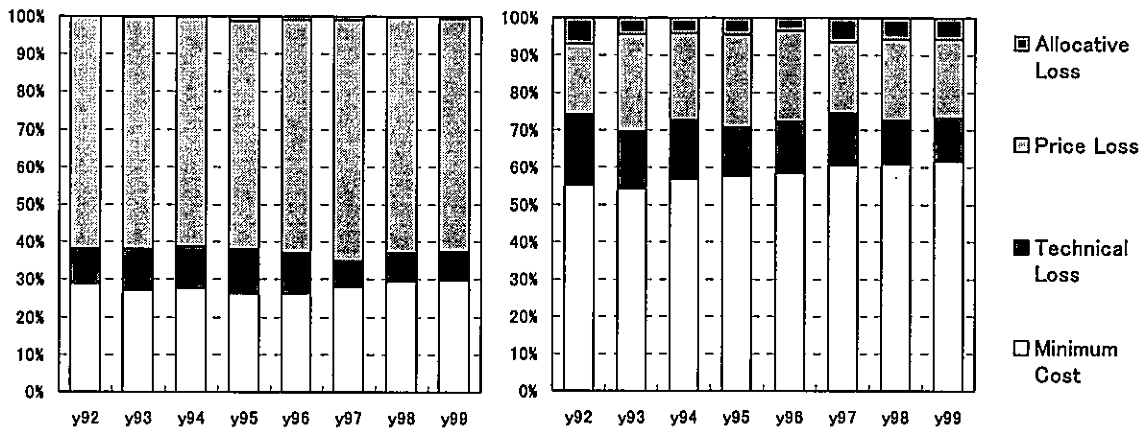
These results indicate that the Japanese average technical efficiency (TE) and allocative efficiency (AE) are superior to their US counterparts; however, the differences are negligible. According to the results of the Wilcoxon test, these differences are insignificant except for TE in 1992, AE in 1992, 1994, and 1999 at the 5% significance level. In contrast, the difference in the price efficiency index between the two countries is very large and the US average is significantly greater than the Japanese one.

Figures 4 and 5 explain the decomposition of the total actual supply cost. While the former is based on the supply cost standardized by net electric power sales (cent/kWh), the latter focuses on the structural ratio of losses.



Japan average US average

Fig. 4: Decomposition of Actual Supply Cost



Japan average US average

Fig. 5: Decomposition of Actual Supply Cost (Ratio Oriented)

Although the Japanese average actual supply cost has been declining over the years, it is nearly twice that of the US average actual supply cost. It is clearly indicated that the losses due to the differences in the input price levels are much larger than those of the others in Japan as well as the losses in the US. In contrast to the price difference loss, losses due to technical and allocative inefficiencies in Japan are comparatively smaller than those in the US; however, there exist no significant differences as mentioned previously. These results imply that the comparatively higher electricity price in Japan is caused by higher input factor prices and not technical inefficiency.

In the economic context, market prices are uncontrollable and treated as a given condition. The loss due to the price difference, as shown in Figure 4, might be uncontrollable for DMUs. For instance, the price gap might be caused by the difference in the business conditions between Japan and the US. It is common knowledge that Japanese utilities spend considerable expenditure to maintain superior reliability of electricity supply and pollution control. They also have to protect against natural disasters, such as earthquakes, typhoons, snowfall, and salt damage, which occur frequently. Furthermore, Japan is not rich in natural resources and relies on imports for the majority of generation fuel, while the US utilities can procure cheap fuel domestically. These business conditions must be the cause of the high cost of electricity supply of Japanese utilities. However, at the same time, inefficiency of the utilities might result in higher input prices, e.g., they might purchase equipment at unnecessarily higher prices. This study does not enable the identification of the primary cause of higher input prices; it only shows that a higher input price has a greater effect on the higher supply cost than productive inefficiency.

4 Extensions of the Model

We extend our basic model described in Section 2 to the factor-oriented decomposition and evaluate the loss due to scale efficiency.

4.1 Factor-oriented Decomposition

By focusing on each input factor, the decomposition can be examined in greater detail. The losses explained in Eq. (16) are redefined as follows:

$$L_{io}^{*} = w_{io}x_{io} - w_{io}(\theta^{*}x_{io} - s_i^{-*}) = w_{io}(x_{io} - \theta^{*}x_{io} + s_i^{-*}) \tag{19}$$

$$L_{io}^{**} = \bar{x}_{io} - (\rho^{*}\bar{x}_{io} - t_i^{-*}), \tag{20}$$

where L_{io}^{*} and L_{io}^{**} are losses due to the technical and price inefficiencies for input i, respectively, and $L_o^{*} = \sum_{i=1}^{m} L_{io}^{*}$ and $L_o^{**} = \sum_{i=1}^{m} L_{io}^{**}$. Considering the losses by factor, we can further decompose the actual total cost (C_o) into losses in greater detail than in Eq. (16) as follows:

$$C_o = \sum_{i=1}^{m} L_{io}^{*} + \sum_{i=1}^{m} L_{io}^{**} + L_o^{***} + C_o^{***}. \tag{21}$$

Furthermore, these losses can be classified into factor-oriented losses as follows:

$$C_o = \sum_{i=1}^{m} L_{io} + L_o^{***} + C_o^{***}, \tag{22}$$

where L_{io} is the sum of the technical inefficiency loss (L_{io}^{*}) and the price inefficiency loss (L_{io}^{**}) for input i. This decomposition is useful for verifying which input factor cost results in a greater loss. Figure 6 describes the factor-oriented decomposition for Japanese and US utilities in 1999. It is clearly seen that the capital cost loss in Japan is much larger than that in the US.

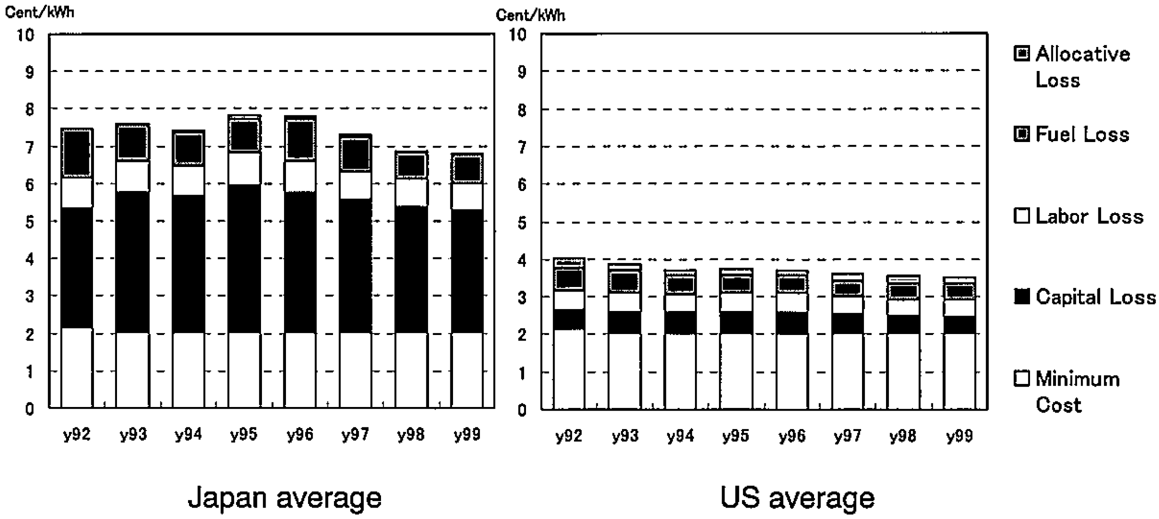


Fig. 6: Factor-oriented Decomposition

4.2 The Loss due to Scale Inefficiency

We can measure scale efficiency using the BCC model (Banker *et al.*., 1984).

$$\begin{aligned} &[\text{BCC}] \quad \eta^* = \min \eta \\ &\text{subject to } \eta x_o = X\lambda + s^- \\ &\qquad y_o = Y\lambda - s^+ \\ &\qquad e\lambda = 1 \\ &\qquad \lambda \geq 0, s^- \geq 0, s^+ \geq 0. \end{aligned} \tag{23}$$

The projection is given by

$$[BCC - projection] \quad x_o^{B^*} = \eta^* x_o, \quad y_o^{B^*} = y_o. \tag{24}$$

Generally, scale inefficiency is measured as the gap between the CCR and BCC frontiers. In this paper, we focus on the radial gap; therefore, the BCC projection does not account for slacks[7]. In order to measure scale inefficiency, we use the CCR-projection without considering slacks as follows:

[7] If the BCC slacks are considered in the BCC-projection, we cannot avoid the case that the BCC-projection is smaller than that of CCR, even though the CCR-projection considers CCR slacks. Furthermore, in the case that we use the slack, considering CCR and BCC projection, we cannot obtain the "radial gap" between the CCR and BCC models.

$$[CCR-projection]\;\; x_o^{C*}=\theta^* x_o,\;\; y_o^{C*}=y_o. \tag{25}$$

The cost of the projected x_o^{B*} and x_o^{C*} are obtained as follows:

$$C_o^{B*}=\sum_{i=1}^m w_{io}x_{io}^{B*}=\eta^*\sum_{i=1}^m w_{io}x_{io}=\eta^* C_o \le C_o \tag{26}$$

$$C_o^{C*}=\sum_{i=1}^m w_{io}x_{io}^{C*}=\theta^*\sum_{i=1}^m w_{io}x_{io}=\theta^* C_o \le C_o \tag{27}$$

$$C_o^{C*}=\theta^* C_o \le \eta^* C_o = C_o^{B*}. \tag{28}$$

The loss due to scale inefficiency is expressed as the gap between C_o^{B*} and C_o^{C*} as follows:

$$L_o^{s*}=C_o^{B*}-C_o^{C*}(\ge 0). \tag{29}$$

We defined the loss due to pure technical inefficiency as the remaining part by subtracting L_o^{s*} from L_o^{*} [8] as follows:

$$L_o^{p*}=L_o^{*}-L_o^{s*}(\ge 0). \tag{30}$$

Finally, the cost decomposition proceeds as follows:

$$C_o=L_o^{p*}+L_o^{s*}+L_o^{**}+L_o^{***}+C_o^{***}. \tag{31}$$

Figure 7 shows the further decomposition including the scale inefficiency loss for the Japanese and the US utilities in 1999.

[8] In other words, we define the loss due to pure technical inefficiency including slacks of the CCR Model.

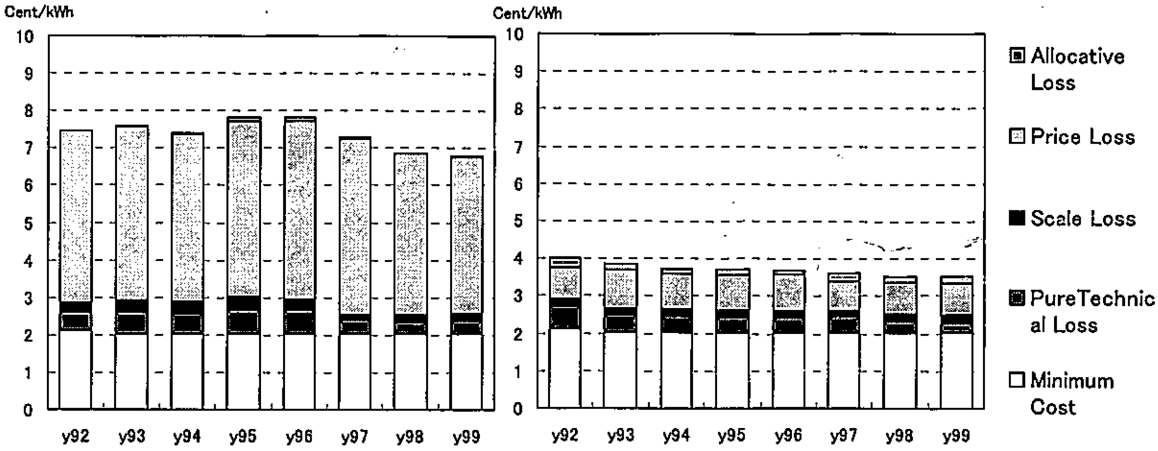


Fig. 7: Further Decomposition including Scale Inefficiency

5 Conclusion

In this paper, we decompose the observed actual total cost into the minimum cost and losses due to technical inefficiency, input price differences, and inefficient cost mix using traditional CCR, New Tech, and New Cost models. The combination of these models enables us to clarify the influence of not only technical inefficiency due to input overuse (or output underproduction) but also the comparatively higher input factor price on the total supply cost. The latter cannot be identified under the assumption of given uniform input factor prices. For instance, it is very common that there exist price differences among countries. Moreover, when we observe the actual market, these differences sometimes exist even within a country. However, it is impossible to measure the effect of the price differences under a traditional framework.

Applying the new combined model to the data of the electric utilities, this paper has succeeded in obtaining a good performing index for the price level. This implies that this model is effective in examining the cost performance of the concerned DMUs. As a result of decomposition, it is clarified that the higher electric price in Japan is caused by the comparatively higher input factor prices, rather than by the technical and allocative inefficiencies.

As we have shown in the further extension, this model has the potential to be used in a broad range of applications, and it is also applicable to other industries to analyze the main cause of inefficiency due to supply cost.

As future research subjects, we should identify the reason of inefficiency measured by DEA, which is caused by uncontrollable factors such as business environment, or the "real" inefficiency of DMUs. As mentioned in Section 3, the gap in input factor prices between Japan and the US might be caused by several factors, and it is difficult to determine whether this gap can be reduced by the efforts of DMUs. From the viewpoint of applicability and implication to company management, it would be an important issue to resolve.

Throughout this paper, we have employed radial-based models, i.e., CCR and BCC, for measuring the technical efficiencies. We can, however, utilize the non-radial SBM (slacks-based) models for this purpose. Comparisons of the results obtained by the two approaches would be an interesting subject for future research.

References

Banker, R.D., Charnes A. and Cooper W.W. (1984) "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis," *Management Science*, 30, 1078-1092.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) "Measuring the Efficiency of Decision Making Units," *European Journal of Operations Research*, 2, 429-444.

Färe, R. and Grosskoph, S. (1988) "Measuring Shadow Price Efficiency," in A. Dogramaci and R. Färe, eds., *Application of Modern Production Theory: Efficiency and Productivity*, 223- 234, Kluwer Nijhoff.

Färe, R., Grosskoph, S. and Lovell, C.A.K. (1985) *The Measurement of Efficiency of Production*, Boston: Kluwer Nijhoff.

Färe, R., Grosskoph, S. and Nelson, J. (1990) "On Price Efficiency" *International Economic Review*, 31:3, 709-720.

Färe, R., Grosskoph, S. and Lovell, C.A.K. (1994) *Production Frontiers*, Cambridge University Press.

Farrell, M.J. (1957) "The Measurement of Productive Efficiency," *Journal of Royal Statistical Society* Series A, 120, 253-381.

Goto, M. and Tsutsui, M. (1998) "Comparison of Productive and Cost Efficiencies Among Japanese and US Electric Utilities," *Omega*, 26, 177-194.

Hattori, T. (2002) "Relative Performance of U.S. and Japanese Electricity Distribution: An Application of Stochastic Frontier Analysis," *Journal of Productivity Analysis*, 18, 269-284.

Tone, K. (2001) "A Slack-Based Measure of Efficiency in Data Envelopment Analysis," *European Journal of Operational Research*, 130, 498-509.

Tone, K. (2002) "A Strange Case of the Cost and Allocative Efficiencies in DEA," *Journal of the Operational Research Society*, 53, 1225-1231.