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Total-factor energy efficiency of regions in Japan

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Abstract

This study computes the regional total-factor energy efficiency (TFEE) in Japan by employing the data envelopment analysis (DEA). A dataset of 47 prefectures in Japan for the period 1993–2003 is constructed. There are 14 inputs, including three production factors (labor employment, private, and public capital stocks) and 11 energy sources (electric power for commercial and industrial use, electric power for residential use, gasoline, kerosene, heavy oil, light oil, city gas, butane gas, propane gas, coal, and coke). GDP is the sole output. Following Fukao and Yue [2000. Regional factor inputs and convergence in Japan—how much can we apply closed economy neoclassical growth models? Economic Review 51, 136–151 (in Japanese)], data on private and public capital stocks are extended. All the nominal variables are transformed into real variables, taking into consideration the 1995 price level. For kerosene, gas oil, heavy oil, butane gas, coal, and coke, there are a few prefectures with TFEEs less than 0.7. The five most inefficient prefectures are Niigata, Wakayama, Hyogo, Chiba, and Yamaguchi. Inland regions and most regions along the Sea of Japan are efficient in energy use. Most of the inefficient prefectures that are developing mainly upon energy-intensive industries are located along the Pacific Belt Zone. A U-shaped relation similar to the environmental Kuznets curve (EKC) is discovered between energy efficiency and per capita income for the regions in Japan.

Keywords: Energy-saving target ratio; Total-factor energy efficiency; Data envelopment analysis

1. Introduction

The 1990s are called the 'lost decade' in Japan. The average annual growth rate of real GDP was 1% in the 1990s, which was lower than that of other industrialized countries. The causes of the depression continue to be controversial. Although the performance of Japan's economy in the 1990s was disappointing, an increase in energy consumption has been observed. As such, it is important to reduce energy consumption without harming economic performance due to the following two reasons.

First, saving energy is an important issue in Japan, because Japan's energy self-sufficiency stands at a low 4%. Japan has traditionally promoted energy conservation after the two oil crises in the 1970s. In the past 30 years, the industrial sector in Japan succeeded in saving energy, but energy consumption in the residential, commercial, and transportation sectors showed upward trends as a result of the pursuit of a comfortable lifestyle.[1]

Second, in accordance with the Kyoto Protocol—an international treaty designed to mitigate global warming—Japan is required to reduce its greenhouse gas emissions by 6% from 1990 levels, on average, during the period 2008–2012. Energy consumption is the main source of carbon dioxide emissions in Japan, and these emissions have increased approximately by 13.1% between 1990 and 2005. Carbon dioxide emissions resulting from energy consumption accounted for 92.6% of greenhouse gas emissions in 2005.[2] To reduce carbon dioxide emissions,

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[1]For a discussion on the energy-efficiency policy of Japan and other OECD countries, see Geller et al. (2006).

[2]Nuclear power generation provides approximately one-third of Japan's electric power. The government plans to expand nuclear power generation, because it does not emit carbon dioxide at the time of power generation. However, public opinion with regard to its construction has been negative due to accidents and the falsification of records in recent years.

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the implementation of energy efficiency has become an important political issue in Japan.

Because the usage of energy differs across areas, regional policies to reduce greenhouse gases play an important role. According to the Law Concerning the Promotion of the Measures to Cope with Global Warming, local governments in Japan shall strive to formulate plans on measures to limit greenhouse gas emissions in accordance with the natural and social conditions of their areas. A government agency subsidizes regional energy-saving plans through local governments.[3] Although the local governments estimate energy consumption in an area and set a goal for reducing greenhouse gases, the problem lies in the fact that governments are not aware of regional energy efficiency.

Although the energy consumption of Japan as a whole has increased recently, Japan is more energy efficient than other industrialized countries.[4] In 2003, the size of the Japanese economy had doubled as compared with 1973, whereas energy consumption of the manufacturing industry increased slightly. In 2003, if Japan's primary energy consumption (on crude oil equivalent basis) per real GDP is taken as 1, then that of the United States is 2.08, that of United England is 1.43, that of France is 1.36, and that of Germany is 2.41.[5]

Japan's national energy policy aims to achieve three underlying goals, the 3Es: energy security, environmental protection, and economic growth.[6] For the third target, the Japanese government has been undertaking the liberalization and deregulation of the energy markets in the past 10 years. One of the reasons for this is that petroleum, electricity, and gas prices in Japan were higher than those in other countries. Liberalization and deregulation have reduced costs of electricity and gas and increased the efficiency of the energy markets. As a result, these policies have stimulated economic growth. The effects of the above energy policies are the major concerns. For example, Sueyoshi and Goto (2001) empirically examined the performance of electric power companies in Japan by employing data envelopment analysis (DEA). The implementation of energy saving requires data on the energy consumption of each sector across areas; however, such statistics do not exist. Kainou (2006) estimated energy consumption and carbon dioxide emissions for 47 regions and 15 sectors in Japan. This estimation provides basic information useful for regional, environmental, and QJ;energy policies and enables a comparison among regions. However, it does not calculate the absolute efficiency score of energy use in each district.

This paper analyzes the energy efficiency of the Japanese economy by employing DEA. The energy efficiency of areas in Japan is obtained from the total-factor framework. Not much attention has been paid to regional energy efficiency in Japan, and to our knowledge, there has been no study applying the DEA method to measure regional energy efficiency in Japan. Our results identify the areas for which the government needs to improve the energy efficiency and provide useful insights with respect to regional energy and environmental policies. The paper is organized as follows: Section 2 gives our methodology of DEA. Section 3 describes the data we use for our analysis. Section 4 presents the empirical results and discussions. Finally, Section 5 concludes this paper.

2. Methodology of the DEA

This paper uses DEA to determine the input targets for each Japanese region by comparing the annual efficiency frontier that is constituted by all the Japanese regions in each year. Since the frontier is an input-reducing focus, this paper uses input-orientated measures following Farrell's (1957) original ideas. In order to pursue overall technical efficiency with energy inputs, our study adopts the constant returns to scale (CRS) DEA model (Charnes et al., 1978).

Our measure of relative efficiency is based on non-parametric techniques (Färe et al., 1994). Let us first define some mathematical notations: there are K inputs and M outputs for each of the N objects. The ith object is represented by the column vectors x_i and y_i, respectively. The $K \times N$ input matrix X and the $M \times N$ output matrix Y represent the data for all the N objects. The input-oriented CRS DEA model then solves the following linear programming problem for object i in each year:

$$\begin{aligned} D(y_i, x_i) = \mathrm{Min}_{\theta,\lambda} \quad & \theta \\ \text{subject to} \quad & -y_i + Y\lambda \geqslant 0, \\ & \theta x_i - X\lambda \geqslant 0, \\ & \lambda \geqslant 0, \end{aligned} \tag{1}$$

where θ is a scalar and λ is an $N \times 1$ vector of constants.

The value of θ is the overall technical efficiency (OTE) score for the ith object, with $0 \leqslant \theta \leqslant 1$. The value of unity indicates a point on the frontier and hence the technically efficient regions, in accordance with Farrell's (1957) definition. The frontier is a piecewise linear isoquant, determined by the observed data points of the same year, i.e., all the regions in this study of the same year. The region that constructs the frontier is the 'best practice' among those observed regions in that year. The weight vector λ serves to form a convex combination of observed inputs and outputs.

Fig. 1 illustrates the efficiency measurement: each point on Fig. 1 represents a combination of inputs that all produce the same level of output. Regions C and D are on

[3]The New Energy and Industrial Technology Development Organization (NEDO), a quasi-public organization under METI, subsidizes local authorities to establish energy conversation visions; from 2000 to 2006, 215 of Japan's 1891 local authorities received this subsidy.

[4]In the 1990s, the total final energy consumption increased by 13.4%.

[5]Numbers are quoted from METI (2006, p. 150). They are based on the original data of IEA (2005). Primary energy equivalent of nuclear electricity is calculated by the conversion method of IEA (2005).

[6]See IEA (2003) for an overview of the Japan's energy policy.

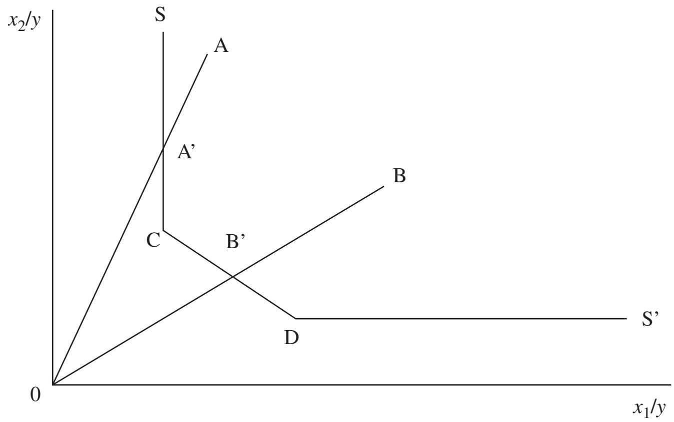

Fig. 1. Efficiency measurement in the CRS DEA model.

the frontier and they cannot maintain the given output level by further reducing their inputs. Regions A and B are therefore inefficient regions.

An important issue in efficiency studies is the credibility of the assumption that all production processes can actually reach the best practice production frontier (Zofío and Prieto, 2001; Chien and Hu, 2007). In the present study, when measuring energy efficiency, it is assumed that the best practice is accessible to all regions. This assumption seems to be adequate since only Japanese regions are considered. Currently, specialized journals, technological fairs, the global marketing strategies of multinationals, etc., guarantee that new innovations are readily available to all regions (Zofío and Prieto, 2001; Chien and Hu, 2007).

The set on the frontier is the 'best practice' production among the observed regions. The inefficient region can reduce inputs by the amount indicated by the arrow and still remain in the input set (Boyd and Pang, 2000). With respect to the ith region, its distance (amount) in relation to the projected point on the frontier by radial reduction without reducing the output level, $(1-\theta)x_i$, is known as 'radial adjustment'. We can illustrate this through Fig. 1. Point B is the actual input set and point B′ is the ideal or best practice input set for region B by reducing the radial adjustment BB′.

When the frontier runs parallel to the axes, this could lead to a problem. In Fig. 1, point A′ is the best practice for region A by reducing the radial adjustment AA′. Point A′ can reduce some input so as to maintain the same output level. The reduced amount is called 'input slack' (by the amount CA′). For region A, the best practice is point C, instead of point A′, by reducing the radial adjustment AA′ and slack CA′.

The summation of slack and radial adjustments is the total amount ('target') that can be reduced without decreasing the output levels. With respect to energy input, the above summation is called the 'energy-saving target' (EST). The formula is as follows:

$$\mathrm{EST}_{(i,t)} = \text{Slack adjustment}_{(i,t)} + \text{Radial adjustment}_{(i,t)}, \tag{2}$$

where $\mathrm{EST}_{(i,t)}$ refers to the EST in the ith region and the tth year.

An inefficient region can reduce or save EST in energy use without reducing real economic growth. The CRS model may suggest the slack and radial adjustments of any individual input for all objects to be efficient. Since the actual practice can be improved to the best practice, the actual energy consumption is always larger than or equal to the ideal energy input.

Efficiency is generally defined in terms of the ratio with which the best practice compares with the actual operation. The indicator of energy efficiency should therefore be the ratio of the aggregate energy-saving target from Eq. (2) to the actual energy consumption. The amount of total adjustments in energy input is regarded as the inefficient portion of actual energy consumption. Based on the slack and radial adjustments of energy obtained from DEA, we can calculate the energy-saving target ratio (ESTR), considering other factors simultaneously. The target inputs of an object in a year are determined by comparing its actual inputs to the efficiency frontier in that year. The formula is as below:

$$\mathrm{ESTR}_{(i,t)} = \frac{\text{Energy-saving target}_{(i,t)}}{\text{Actual energy input}_{(i,t)}}, \tag{3}$$

where $\mathrm{ESTR}_{(i,t)}$ refers to the ESTR in the ith region and the tth year.

As Eq. (3) shows, the ESTR represents each region's inefficient level of energy consumption. Since the minimal value of EST is zero, the value of ESTR lies between zero and unity. The total-factor energy efficiency (TFEE) index originally proposed by Hu and Kao (2007) and Hu and Wang (2006) has the following relation with ESTR:

$$\mathrm{TFEE}_{(i,t)} = 1 - \mathrm{ESTR}_{(i,t)}, \tag{4}$$

where $\mathrm{TFEE}_{(i,t)}$ refers to the TFEE in the ith region and the tth year. A zero ESTR value indicates a region on the frontier with the best TFEE up to one among the observed regions. A zero ESTR implies that no redundant or over-consumed energy use exists (the target potential is zero) in this region; otherwise, an inefficient region with the value of ESTR larger than zero implies that energy should and could be saved at the same economic growth level. A higher ESTR implies higher energy inefficiency and a higher energy-saving amount.

As mentioned above, many studies criticize the commonly used indicator of energy inefficiency—namely, the energy intensity as a direct ratio of the energy input to GDP for measuring energy efficiency (e.g., Patterson, 1996; Renshaw, 1981). The ratio is only a partial-factor energy-efficiency indicator since energy input is the only input-considered factor. Another argument is that this partial-factor ratio is inappropriate to analyze the impact of changing energy use over time (APERC, 2002). We then compute the energy efficiency by a total-factor framework including other inputs such as labor and capital. A total-factor efficiency indicator provides more information and a more realistic comparative base to examine the de facto situation across regions.

3. Data sources and variable definitions

The DEA is applied to a dataset of 47 prefectures in Japan for the period 1993–2003. Table 1 presents the summary statistics of the inputs and output used in the DEA models. This study employs 14 inputs, including three production factors (labor employment, real private, and real public capital stocks) and 11 energy inputs (electric power for commercial and industrial use, electric power for residential use, gasoline, kerosene, heavy oil, light oil, city gas, butane gas, propane gas, coal, and coke). These energy inputs are all used for final consumption in the regions. The regional GDP is the sole output. The data on private and public capital stocks are unavailable, and hence the data estimated in Fukao and Yue (2000) are extended.

Data on prefectural real GDP and labor (employed persons) are taken from the *Annual Report on Prefectural Accounts* published by the Cabinet Office (2006a). All prices are adjusted to the market prices for the calendar year of 1995. Electric power data for commercial and industrial use and residential use are obtained from the *Handbook of Electric Power Industry* published by the Federation of Electric Power Companies of Japan (1994–2004).[7] Data on propane and butane gas consumption are obtained from the website of Japan LP Gas Association (2007) (http://www.j-lpgas.gr.jp/). Data on city gas consumption by administrative division in Japan are released only by calendar year, which are obtained from *the Annual Statistics of Gas Industry* published by the Agency for Natural Resources and Energy (each year a). Therefore, only the data on city gas consumption are collated by calendar year, whereas data on all other economic and other energy consumption are collated by fiscal year. Data on gasoline, kerosene, gas oil (light oil), and heavy oil are taken from the *Yearbook of Mineral Resources and Petroleum Products Statistics* (METI). There are no official statistics on coal and coke consumption by prefecture. As for them, we use the estimated data in Kainou (2006).

There are no formal statistics on the private and public capital stock by administrative division in Japan. We obtain the extended data estimated by Fukao and Yue (2000), who examined the mechanism of interregional convergence in Japan and estimate the private and public capital stocks by administrative division in Japan from 1955 to 1995.[8] We extend the private capital stock data from 1996 to 2003 and estimate it using their method, which is as follows:

$$K_t^i = K_{t-1}^i + (K_t - K_{t-1})\frac{I_t^i}{I_t}, \tag{5}$$

where K_t^i is the private capital stock of prefecture i at year t; K_t is the nationwide private capital stock; I_t^i is the private firm investment of prefecture i; and I_t is the nationwide private investment. Data on the gross capital stock of private enterprises (K_t) are obtained from the Cabinet Office (2006b).[9] The private firm investments to administrative regions (I_t^i) are from the aforementioned *Annual Report on Prefectural Accounts*. We assume that rate of elimination of capital stock is the same in all regions in each year.

There are also no formal data on nationwide public capital stock. Therefore, we extend the public capital stock data estimated in Fukao and Yue (2000) by the Cabinet Office (2002). Referring to data of Cabinet Office (2002), we extend the national public stock data to 2003, assuming that public capital is durable for 34 years and that public capital faces a disaster at half the number of the durable years (17 years). Note that two public corporations in Japan were privatized in the 1980s. In 1985, Nippon Telegraph and Telephone Public Corporation was privatized to become the Nippon Telegraph and Telephone Corporation (NTT). In addition, in 1987 the Japan National Railway was privatized and split into several railway companies. The computation process of the nationwide public capital stock is as follows:

$$K_t^* = K_{t-1}^* + I_t^* - I_{t-34}^* + INTT_{t-34}^* + IJR_{t-34}^* + B_{t-34+17}^* - BJR_{t-34+17}^* - B_{t-34}^* + BJR_{t-34}^*, \tag{6}$$

where K_t* is the nationwide public capital stock in year t; I_t* is the nationwide public investment of new construction and improvement in year t; B_t* is the nationwide public investment of natural disaster relief expenditure in year t; IJR_t* is investment of new construction and improvement of Japan National Railway at time t; BJR_t* is the investment of Japan National Railway's natural disaster relief expenditure in year t; and $INTT_t$* is investment of new construction and improvement for Nippon Telegraph and Telephone Public Corporation in year t. The nationwide public capital stock at year t (K_t*) extended using the above method is then allocated to each prefecture in the same manner as in the case of private capital stock data as follows:

$$K_t^{i*} = K_{t-1}^{i*} + (K_t^* - K_{t-1}^*)\frac{I_t^{i*}}{I_t^*}. \tag{7}$$

Table 2 presents the correlation coefficients of the input and output variables. The isotonicity property that an output should not decrease with an increase in an input is

[7]To avoid the problem of double counting, we subtract each source of energy consumption used for power generation, with reference to *Outline of Electric Power Supply and Demand* published by the Agency for Natural Resources and Energy (each year b) in Japan.

[8]The data of Fukao and Yue (2000) can be obtained from the following database: http://www.ier.hit-u.ac.jp/~fukao/japanese/data/index.html (in Japanese).

[9]Follwiing Fukao and Yue (2000), we refer to data on the gross capital stock of private enterprises obtained from the Cabinet Office (2006b), the main data source for Japanese capital stock. Note that its depreciation includes the elimination of capital and not capital consumption.

Table 1
Description and summary statistics of variables

Variable	Definition	Unit	Mean	Std Dev	Minimum	Maximum
Output						
y	Total income	Billion yen in 1995 prices	10,843.73	13,826.30	2009.20	88,566.02
Inputs						
x_1	Employed persons	Person	1,337,847.21	1,423,184.49	313,693.00	8,782,396.00
x_2	Private capital stock	Billion yen in 1995 prices	22,324.36	25,983.45	3131.81	166,007.50
x_3	Public capital stock	Billion yen in 1995 prices	16,435.11	13,915.21	4005.28	83,458.06
x_4	Electric power for residential use	Million kWh	5067.27	4964.56	942.00	28,428.00
x_5	Electric power for commercial and industrial use	Million kWh	11,774.85	11,079.22	1763.00	52,955.00
x_6	Gasoline	kL	1,179,741.78	1,019,686.72	268,654.00	7,591,664.00
x_7	Kerosene	kL	612,685.61	654,523.86	60,428.00	4,092,522.00
x_8	Gas oil	kL	896,769.57	752,560.76	140,763.00	4,807,624.00
x_9	Heavy oil	kL	1,050,366.68	950,189.23	57,223.00	5,793,805.00
x_{10}	City gas	Million MJ	20,480.33	40,516.85	515.00	241,405.00
x_{11}	Butane gas	Tons	103,035.14	130,104.53	4914.00	770,696.00
x_{12}	Propane gas	Tons	211,618.90	164,136.00	39,222.00	890,332.00
x_{13}	Coal	1000 ton	368.72	573.48	4.87	2664.36
x_{14}	Coke	1000 ton	851.57	1621.14	0.47	7089.15

Table 2
Correlation coefficients of input and output variables

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
y	0.930	0.990	0.892	0.961	0.920	0.906	0.679	0.860	0.796	0.913	0.801	0.786	0.163	0.179

not violated. Tables 1 and 2 show the summary statistics of these inputs and output.

4. Empirical results

Table 3 shows the result of the overall technical efficiency scores for the administrative regions in Japan. We calculate the TFEE in the case of 11 energy sources as inputs. Due to space constraints, we only present the TFEEs for four energy inputs in Tables 4–7.

Table 3 presents 29 prefectures that have efficiency scores of one for the entire period. These prefectures operate on the Japanese efficiency frontiers and comprise prefectures in rural and metropolitan areas, such as Tokyo and Saitama. These prefectures share a common feature: the proportion of energy-intensive industries to the total number of manufacturers is lower than the nationwide average.[10]

We consider the geographical features of the prefectures. Fig. 2 shows the geographical distribution of the efficient and inefficient regions in Japan. Most of the prefectures that face the Sea of Japan have an efficiency score of one for the entire period (05, 06, 16, 17, 18, 31, 32, 41, 42, and 43). Eight inland prefectures (09, 10, 11, 19, 20, 21, 25, and 29) have an average score of at least 0.97. In particular, six areas with the exception of Gifu (21) and Shiga (25) have an efficiency score of one for the entire period. The reason why the areas along the Sea of Japan and inland are efficient, for the most part, is that industry and population in modern Japan have concentrated on the Pacific side of the archipelago. These areas are collectively known as the Pacific Belt Zone, which encompasses areas from the Tokyo metropolitan area to the city of Kitakyushu in Fukuoka prefecture. Among other things, energy-intensive industries have concentrated on certain areas on the side. It is important that an energy-saving policy be implemented intensively in the Pacific Coast area.

We next consider the relationship between per capita income and energy efficiency. The regions are divided into four groups based on the average per capita income at 1995 market prices. The groups are as follows: low income, 2.5 million yen or lower; lower middle income, 2.5–2.75 million yen; upper middle income, 2.75–3.0 million yen; and high income, 3.0 million yen or higher. Fig. 3 depicts the rates of the efficient areas (more than 0.95) in each group with respect to the technical efficiency score and the TFEE indices of the main energy consumption. A U-shaped relation similar to the environmental Kuznets curve (EKC) is discovered between the TFEE and the per capita income for the regions in Japan. The reason behind this result is as follows. In regions belonging to the high-income group, there are many areas wherein the service industry accounts for a high value added without the use of a considerable amount of energy. Many prefectures in the low-income group do not have industrial zones. Because there are areas

[10] In this paper, chemical, ceramic, iron and steel, metal products, and pulp and paper industries are regarded as energy-intensive industries.

Table 3
Overall technical efficiency scores of Japanese Administrative Regions (1993–2003)

ID	Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
01	Hokkaido	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
02	Aomori	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000
03	Iwate	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
04	Miyagi	0.971	0.991	0.975	0.959	0.957	0.946	0.966	0.975	0.980	0.978	0.982
05	Akita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
06	Yamagata	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Fukushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
08	Ibaraki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.976	0.966	0.963
09	Tochigi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Gunma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	Saitama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Chiba	0.986	0.979	0.956	0.920	0.884	0.885	0.892	0.890	0.838	0.894	0.918
13	Tokyo	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	Kanagawa	1.000	0.974	0.992	0.994	0.958	0.950	0.968	0.984	0.971	1.000	1.000
15	Niigata	0.893	0.894	0.902	0.902	0.846	0.834	0.802	0.784	0.810	0.846	0.859
16	Toyama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	Ishikawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Fukui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
19	Yamanashi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Nagano	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	Gifu	0.990	0.987	0.959	0.977	1.000	1.000	1.000	0.990	0.983	0.990	1.000
22	Shizuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Aichi	0.912	0.919	0.941	0.936	0.874	0.910	0.912	0.964	1.000	1.000	1.000
24	Mie	0.980	0.961	0.980	0.974	0.982	0.977	0.962	0.979	0.952	1.000	1.000
25	Shiga	1.000	1.000	1.000	1.000	1.000	0.991	0.979	0.968	0.911	0.936	0.964
26	Kyoto	0.970	0.970	0.971	0.954	0.919	1.000	1.000	1.000	1.000	1.000	1.000
27	Osaka	1.000	1.000	1.000	1.000	0.980	1.000	1.000	1.000	1.000	1.000	1.000
28	Hyogo	0.924	0.895	0.923	0.926	0.787	0.883	0.852	0.873	0.863	0.865	0.882
29	Nara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	Wakayama	0.884	0.860	0.871	0.863	0.852	0.908	0.819	0.756	0.826	0.921	0.968
31	Tottori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	Shimane	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	Okayama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.986
34	Hiroshima	1.000	1.000	0.995	0.991	0.957	0.956	0.938	0.945	0.943	0.919	0.946
35	Yamaguchi	0.929	0.955	0.946	0.934	0.932	0.963	0.942	0.937	0.924	0.948	0.934
36	Tokushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	Kagawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	Ehime	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	Kouchi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	Fukuoka	0.931	0.969	0.948	0.945	0.937	0.942	0.925	0.933	0.940	0.959	0.975
41	Saga	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	Nagasaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
43	Kumamoto	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
44	Oita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
45	Miyazaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	Kagoshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Okinawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

in some prefectures belonging to the lower and upper middle-income groups that have energy-intensive industries, they are relatively inefficient. The curves of kerosene and heavy oil overlap in Fig. 3. As the per capita income rises, the electric power for commercial and industrial use and coal is used inefficiently. The former is used efficiently in the lower middle- and low-income regions.

We now consider the relationship between regional energy efficiency and the extent of the energy-intensive industry. Prefectures are divided into four groups based on the average ratio of a region's GDP out of energy-intensive industries in the sample period. The groups are as follows: the rate of the group A regions is higher than 10%, that of the group B regions lies between 7.5% and 10%, that of the group C regions lies between 5% and 7.5%, and that of the group D regions is less than 5%. Fig. 4 depicts the rates of the efficient areas (more than 0.95) in each group with respect to the technical efficiency score and the TFEE indices of the main energy consumption. It is clear that the rates of inefficient areas are high in group A where energy-intensive industries dominate, especially with respect to heavy oil and coal.

Table 4
Total-factor energy efficiency in electric power for commercial and industrial use of Japanese Administrative Regions (1993–2003)

ID	Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
01	Hokkaido	1.000	0.489	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
02	Aomori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
03	Iwate	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
04	Miyagi	1.000	1.000	1.000	1.000	0.960	0.942	0.964	0.984	0.944	0.992	0.992
05	Akita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
06	Yamagata	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Fukushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
08	Ibaraki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.804	0.910	0.910
09	Tochigi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Gunma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	Saitama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Chiba	0.616	1.000	0.989	1.000	0.747	0.666	0.676	0.664	0.662	0.750	0.750
13	Tokyo	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	Kanagawa	1.000	1.000	0.664	0.737	0.653	0.666	0.717	0.730	0.757	1.000	1.000
15	Niigata	0.742	1.000	0.766	0.863	0.782	0.773	0.793	0.775	0.844	0.870	0.870
16	Toyama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	Ishikawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Fukui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
19	Yamanashi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Nagano	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	Gifu	1.000	0.489	0.983	1.000	1.000	1.000	1.000	0.800	0.879	0.845	0.845
22	Shizuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Aichi	0.563	1.000	0.527	0.531	0.521	0.542	0.564	0.585	1.000	1.000	1.000
24	Mie	0.820	1.000	0.874	0.891	0.759	0.691	0.667	0.776	0.590	1.000	1.000
25	Shiga	1.000	1.000	1.000	1.000	1.000	0.548	0.447	0.492	0.489	0.481	0.481
26	Kyoto	0.707	1.000	0.782	0.798	0.805	1.000	1.000	1.000	1.000	1.000	1.000
27	Osaka	1.000	1.000	1.000	1.000	0.588	1.000	1.000	1.000	1.000	1.000	1.000
28	Hyogo	0.478	1.000	0.499	0.494	0.727	0.533	0.541	0.600	0.746	0.757	0.757
29	Nara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	Wakayama	1.000	1.000	1.000	0.992	0.936	0.823	0.837	0.835	0.906	0.965	0.965
31	Tottori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	Shimane	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	Okayama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
34	Hiroshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
35	Yamaguchi	1.000	1.000	0.957	0.916	0.870	0.999	0.828	0.987	1.000	0.989	0.989
36	Tokushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	Kagawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	Ehime	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	Kouchi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	Fukuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
41	Saga	1.000	0.489	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	Nagasaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
43	Kumamoto	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
44	Oita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
45	Miyazaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	Kagoshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Okinawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

To clarify the characteristics of the inefficiency in prefectures, we describe the five most inefficient prefectures based on the average scores of the 11-year period. The prefecture with the lowest efficiency score is Niigata (15), an industrial city that faces the Sea of Japan. Its main industry is metal manufacturing. The percentage of fabricated metal products in the value of manufactured goods shipments in Niigata is nearly double the national average. Another feature of Niigata is the mining industry. Niigata is ranked as the top producer of both crude oil and natural gas in Japan. These natural resources are rare in Japan and have facilitated the development of iron and chemical factories.

Wakayama (30) is the most inefficient prefecture after Niigata. Many large factories such as Kao, Sumitomo Metal Industries, Mitsubishi Electric, and Tonen General (a company that is part of the Exxon Mobil group) are located in Wakayama. A distinctive feature of Wakayama is that chemical and allied products, petroleum and coal products, and iron and steel totally account for approximately half of the total manufacturing production in Wakayama.

Table 5
Total-factor energy efficiency in kerosene of Japanese Administrative Regions (1993–2003)

ID	Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
01	Hokkaido	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
02	Aomori	1.000	1.000	1.000	1.000	1.000	1.000	0.559	1.000	1.000	1.000	1.000
03	Iwate	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
04	Miyagi	0.818	0.798	0.855	0.898	0.874	0.899	0.779	0.753	0.913	0.860	0.860
05	Akita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
06	Yamagata	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Fukushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
08	Ibaraki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
09	Tochigi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Gunma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	Saitama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Chiba	0.441	0.461	0.667	0.725	0.516	0.513	0.507	0.553	0.890	1.000	1.000
13	Tokyo	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	Kanagawa	1.000	0.504	0.491	0.593	0.564	0.755	0.618	0.634	0.723	1.000	1.000
15	Niigata	0.302	0.311	0.295	0.346	0.352	0.477	0.436	0.485	0.777	0.872	0.872
16	Toyama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	Ishikawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Fukui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
19	Yamanashi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Nagano	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	Gifu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	Shizuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Aichi	0.768	0.697	0.654	0.698	0.848	1.000	1.000	1.000	1.000	1.000	1.000
24	Mie	1.000	1.000	1.000	1.000	0.963	1.000	1.000	1.000	1.000	1.000	1.000
25	Shiga	1.000	1.000	1.000	1.000	1.000	0.778	0.815	0.794	0.964	1.000	1.000
26	Kyoto	0.709	0.807	0.762	0.811	1.000	1.000	1.000	1.000	1.000	1.000	1.000
27	Osaka	1.000	1.000	1.000	1.000	0.978	1.000	1.000	1.000	1.000	1.000	1.000
28	Hyogo	0.495	0.501	0.445	0.449	0.933	0.887	0.916	1.000	1.000	1.000	1.000
29	Nara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	Wakayama	0.763	0.746	0.936	0.938	1.000	0.909	0.908	1.000	1.000	0.856	0.856
31	Tottori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	Shimane	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	Okayama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
34	Hiroshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
35	Yamaguchi	1.000	1.000	1.000	1.000	1.000	0.980	0.850	1.000	1.000	1.000	1.000
36	Tokushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	Kagawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	Ehime	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	Kouchi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	Fukuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
41	Saga	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	Nagasaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
43	Kumamoto	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
44	Oita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
45	Miyazaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	Kagoshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Okinawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

After Niigata and Wakayama, Hyogo (28) is the most inefficient prefecture. Hyogo prefecture is one of the leading industrial prefectures in Japan. Major Japanese companies such as Kawasaki Heavy Industries, Kobe Steel, Ishikawajima-Harima Heavy Industries, Toshiba, Fujitsu, and Mitsubishi Electric Corporation are located in Hyogo. Its main industries include iron and steel, chemical and allied products, and general machinery. In particular, the proportion of iron and steel production in Hyogo to total manufacturing production is nearly twice as high as the nationwide average.

Chiba (12) is the fourth most inefficient prefecture. Chiba prefecture is one of the leading industrial prefectures in Japan and has developed around the petrochemical complex located in Tokyo Bay. Many leading Japanese companies such as Nippon Steel, JFE Steel, Sumitomo Chemical, Mitsui Chemicals, and Cosmo Oil, are located in Chiba. Chemical and allied products, petroleum and coal products, and iron, steel, and fabricated metal products totally account for approximately half of the total manufacturing production in Chiba.

Table 6
Total-factor energy efficiency in heavy oil of Japanese Administrative Regions (1993–2003)

ID	Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
01	Hokkaido	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
02	Aomori	1.000	1.000	1.000	1.000	1.000	1.000	0.926	1.000	1.000	1.000	1.000
03	Iwate	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
04	Miyagi	0.680	0.610	0.591	0.606	0.572	0.660	0.698	0.581	0.625	0.711	0.711
05	Akita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
06	Yamagata	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Fukushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
08	Ibaraki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.499	0.502	0.502
09	Tochigi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Gunma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	Saitama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Chiba	0.336	0.304	0.529	0.522	0.336	0.387	0.411	0.410	0.575	0.534	0.534
13	Tokyo	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	Kanagawa	1.000	0.954	0.966	1.000	0.705	0.834	1.000	1.000	1.000	1.000	1.000
15	Niigata	0.491	0.430	0.413	0.447	0.366	0.486	0.550	0.567	0.588	0.640	0.640
16	Toyama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	Ishikawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Fukui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
19	Yamanashi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Nagano	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	Gifu	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	Shizuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Aichi	0.786	0.871	0.710	0.732	0.735	0.815	0.852	0.741	1.000	1.000	1.000
24	Mie	0.435	0.524	0.517	0.574	0.456	0.560	0.457	0.723	0.471	1.000	1.000
25	Shiga	1.000	1.000	1.000	1.000	1.000	0.601	0.622	0.618	0.736	0.822	0.822
26	Kyoto	0.952	0.931	0.814	0.817	0.809	1.000	1.000	1.000	1.000	1.000	1.000
27	Osaka	1.000	1.000	1.000	1.000	0.998	1.000	1.000	1.000	1.000	1.000	1.000
28	Hyogo	0.756	0.766	0.777	0.802	0.757	1.000	1.000	0.963	0.952	1.000	1.000
29	Nara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	Wakayama	0.706	0.868	0.614	0.577	0.576	1.000	0.381	0.690	0.471	0.480	0.480
31	Tottori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	Shimane	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	Okayama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
34	Hiroshima	1.000	1.000	1.000	1.000	1.000	0.878	0.983	1.000	1.000	1.000	1.000
35	Yamaguchi	0.435	0.472	0.416	0.446	0.479	0.355	0.489	0.292	0.352	0.362	0.362
36	Tokushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	Kagawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	Ehime	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	Kouchi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	Fukuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.910	1.000	1.000
41	Saga	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	Nagasaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
43	Kumamoto	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
44	Oita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
45	Miyazaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	Kagoshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Okinawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Yamaguchi (35) is the last of the five most inefficient prefectures. Mitsui Chemicals and Taiheiyo Cement Co. originated in Yamaguchi. Furthermore, the heavy and chemical industry has historically developed in Yamaguchi. Its major industries include chemical and allied products, ceramic, stone and clay products, and iron and steel. These three sectors account for about 30% of the total manufacturing production in Yamaguchi. In particular, the proportion of petroleum and coal products to total manufacturing production is nearly five times as high as the nationwide average.

Several observations from the above descriptions reveal that the inefficient regions are concentrated on energy-intensive industries such as iron and steel, chemical, and ceramic. Energy efficiency depends on the industrial structure in areas. To improve energy efficiency, the national and local governments must endeavor to change the industrial structure from energy-intensive industries to others. Service and high value-added industries should be promoted in these energy-inefficient regions. Energy-conserving equipment and technologies should be first applied to the industries in these energy-inefficient regions.

Table 7
Total-factor energy efficiency in coal of Japanese Administrative Regions (1993–2003)

ID	Name	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
01	Hokkaido	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
02	Aomori	1.000	1.000	1.000	1.000	1.000	1.000	0.497	1.000	1.000	1.000	1.000
03	Iwate	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
04	Miyagi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
05	Akita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
06	Yamagata	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
07	Fukushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
08	Ibaraki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.305	0.297	0.297
09	Tochigi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
10	Gunma	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
11	Saitama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
12	Chiba	0.256	0.327	0.440	0.188	0.249	0.138	0.113	0.112	0.089	0.032	0.032
13	Tokyo	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
14	Kanagawa	1.000	0.921	1.000	0.574	0.742	0.582	0.320	0.342	0.444	1.000	1.000
15	Niigata	0.278	0.246	0.222	0.199	0.211	0.226	0.206	0.144	0.053	0.060	0.060
16	Toyama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	Ishikawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
18	Fukui	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
19	Yamanashi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
20	Nagano	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	Gifu	0.758	0.722	1.000	0.628	1.000	1.000	1.000	0.350	0.408	0.337	0.337
22	Shizuoka	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
23	Aichi	0.371	0.085	0.158	0.141	0.094	0.182	0.230	0.414	1.000	1.000	1.000
24	Mie	1.000	1.000	1.000	0.907	1.000	0.486	0.793	0.465	0.762	1.000	1.000
25	Shiga	1.000	1.000	1.000	1.000	1.000	0.427	0.233	0.413	0.361	0.446	0.446
26	Kyoto	1.000	0.184	0.106	0.111	0.177	1.000	1.000	1.000	1.000	1.000	1.000
27	Osaka	1.000	1.000	1.000	1.000	0.234	1.000	1.000	1.000	1.000	1.000	1.000
28	Hyogo	0.013	0.014	0.015	0.013	0.081	0.014	0.014	0.048	0.046	0.022	0.022
29	Nara	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
30	Wakayama	0.224	0.245	0.546	0.052	0.048	0.034	0.020	0.027	0.027	0.039	0.039
31	Tottori	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
32	Shimane	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
33	Okayama	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
34	Hiroshima	1.000	1.000	0.144	0.117	0.254	0.583	0.340	0.433	0.403	0.578	0.578
35	Yamaguchi	0.119	0.188	0.093	0.088	0.226	0.089	0.141	0.067	0.092	0.143	0.143
36	Tokushima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
37	Kagawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
38	Ehime	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
39	Kouchi	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
40	Fukuoka	0.111	0.070	0.063	0.067	0.069	0.084	0.087	0.367	0.201	0.624	0.624
41	Saga	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
42	Nagasaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
43	Kumamoto	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
44	Oita	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
45	Miyazaki	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
46	Kagoshima	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
47	Okinawa	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

We next consider the main energy consumption. Five of the most inefficient prefectures in terms of TFEE in heavy oil for the sample period are Yamaguchi (35), Chiba (12), Niigata (15), Mie (24), and Wakayama (30). The reason for this is that the energy-intensive industries have developed in these five areas and that heavy oil is a major input in their production. In particular, most of the scores for Yamaguchi, Chiba, and Mie in the 11 years are less than 0.5, implying that these three prefectures have operated at efficiencies of less than 50% of that for the areas in the efficient frontiers. The TFEE scores of heavy oil in these inefficient regions have improved in the sample period. Five prefectures with the least TFEE in coal in the sample period are Hyogo (28), Wakayama (30), Yamaguchi (35), Niigata (15), and Chiba (12). The reason for this is the same as that in the case of heavy oil. The average TFEE score of these prefectures is an extremely low 0.2. The consumption of coal in these prefectures is extremely high and that in most of the remaining prefectures is very low. These results might be induced by the fact that the consumption of coal differs greatly across regions. Five prefectures with the lowest TFEEs of electric power for industrial use in the

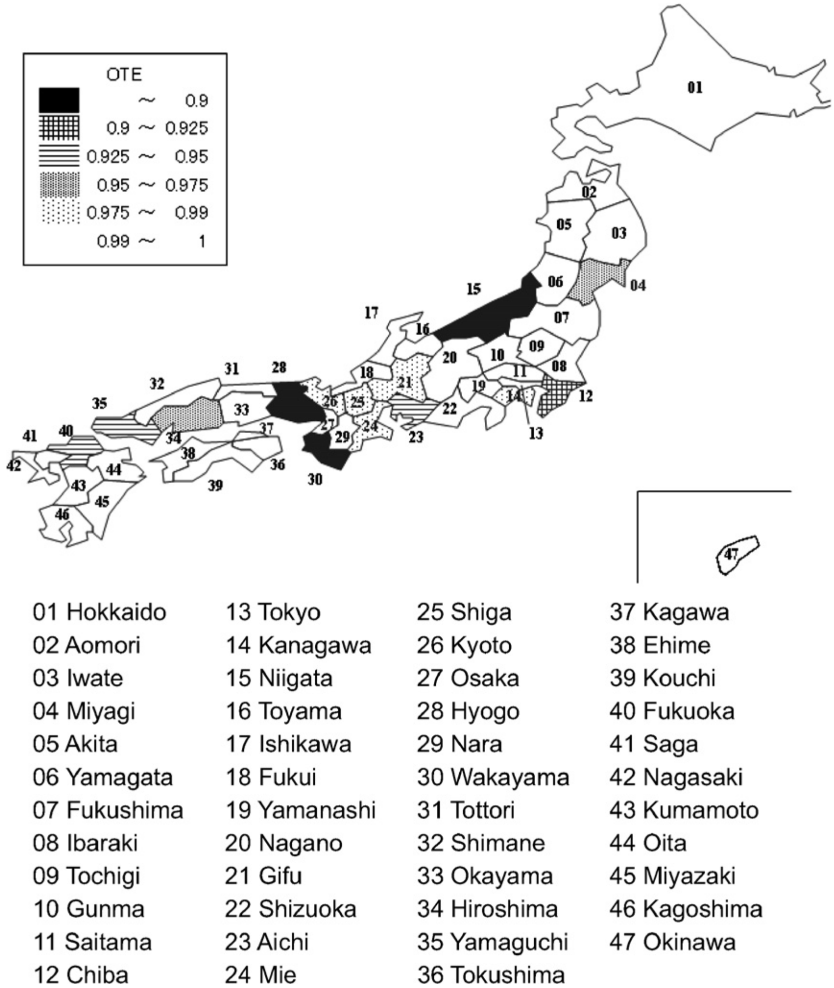

Fig. 2. Geographic distribution of efficient and inefficient regions in Japan.

sample period are Hyogo (28), Aichi (23), Shiga (25), Chiba (12), and Kanagawa (14). These prefectures score poorly in a year in the sample period. Most of these areas overlap with the areas mentioned above.

5. Conclusions

This study analyzes the regional TFEE in Japan by using DEA. The efficiency frontier is constructed by using DEA based on data on energy sources and other inputs. A dataset of 47 prefectures in Japan for the period 1993–2003 is constructed. There are 14 inputs, including three production factors (labor employment, private, and public capital stocks) and 11 energy sources (electric power for commerical and industrial use, electric power for residential use, gasoline, kerosene, heavy oil, light oil, city gas, butane gas, propane gas, coal, and coke). GDP is the sole output. Following Fukao and Yue (2000), data on private and social capital stocks are extended. All the nominal variables are transformed into real variables at 1995 price levels.

A U-shaped relation similar to the EKC theory is discovered between the overall technical efficiency and the per capita income for regions in Japan. Many areas with dominant energy-intensive industries are energy inefficient. For kerosene, gas oil, heavy oil, butane gas, and propane gas, there are a few prefectures with TFEEs less than 0.5. Chiba ranks in the bottom three on all nine energy inputs. Most of the regions along the Sea of Japan and in the inland are almost all energy efficient. The Pacific Belt Zone has most of the inefficient prefectures that mainly develop upon energy-intensive industries.

In order to reduce carbon dioxide, the Japanese government has promoted to maintain or even increase the share of electricity generated by nuclear power, approximately up to one-third. However, this energy policy may not work well since the construction of any new nuclear power plant is opposed by the public, because of worry about its safety from the public. The government also promotes the extension of renewable energy resources (such as solar, wind, biofuel, etc.). However, high cost and technical difficulties of biofuel are major hurdles against utilizing renewable energy. Because Japanese energy policies face substantial difficulties, energy-efficiency improvement is an important issue. To save energy and

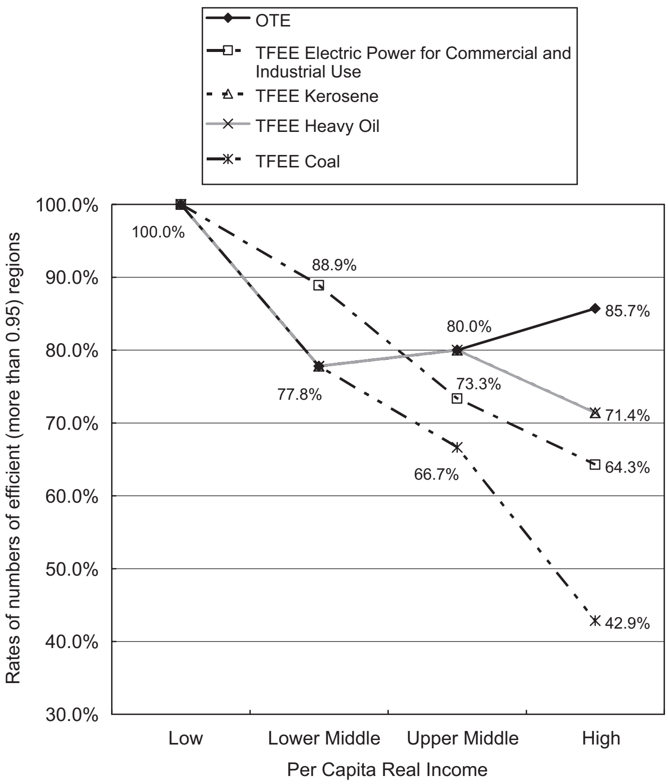

Fig. 3. Relationship between per capita income and technical efficiency.

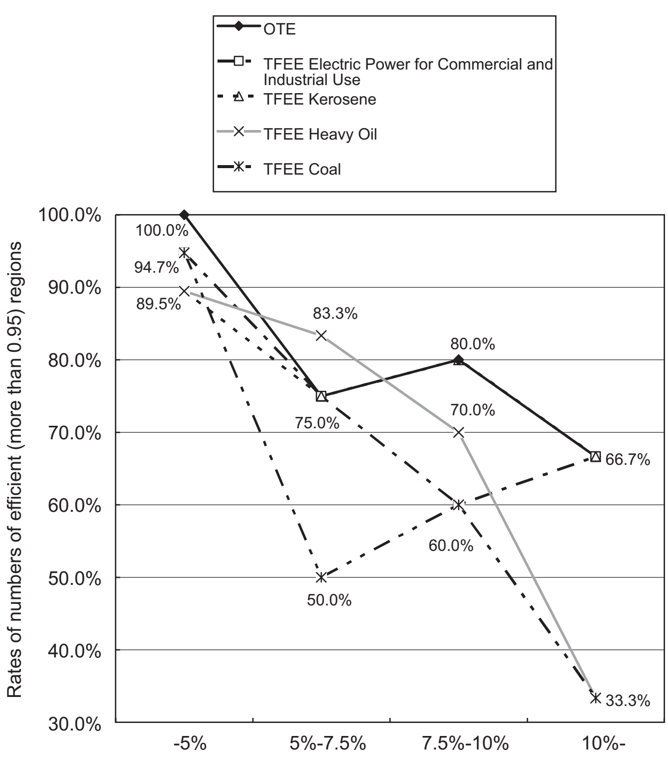

Fig. 4. Relationship between energy-intensive industries and technical efficiency.

reduce carbon dioxide emissions, the national and local governments should promote the improvement of efficiency for energy-intensive industries in the Pacific Belt Zone and Niigata and/or change the industrial structure from energy-intensive industries to others such as service industries.[11]

Further research is needed to examine the industry-specific energy efficiency in each region. This paper uses the total energy consumption in each area of the industrial, commercial, transportation, and residential sectors. The energy consumption of sectors other than the industrial sector must be carefully considered. First, cooling and heating energy consumption in residential and commercial buildings varies across areas. Because the Japanese archipelago runs north and south, the difference in temperature varies considerably across regions. Second, it is somewhat difficult to specify the purpose of energy consumption in the transportation sector across areas. Gasoline and gas oil sold in an area are used as fuel for automobile transportation, not only within the area but also outside.

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[11]A relocation of an energy-intensive industry to another area or country may lead to carbon leakage.

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