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# Total-factor energy productivity growth of regions in Japan

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ABSTRACT

This article computes the energy productivity changes of regions in Japan using total-factor frameworks based on data envelopment analysis (DEA). Since the traditional DEA-Malmquist index cannot analyze changes in single-factor productivity changes under the total-factor framework, we apply a new index proposed by Hu and Chang [2009. Total-factor energy productivity growth of regions in China. Energy Policy, submitted for publication]: a total-factor energy productivity change index (TFEPI) that integrates the concept of the total-factor energy efficiency index into the Malmquist productivity index (MPI). Moreover, we separate TFEPI into change in relative energy efficiency, or the 'catching up effect,' and shift in the technology of energy use, or the 'innovation effect.' The data from 47 prefectures during the period of 1993–2003 are used to compute the TFEPI and its components for 4 kinds of energy. The TFEPI of electric power for commercial and industrial use changes −0.6% annually, which can be separated into a total-factor energy efficiency change of 0.2% and a technical change of −0.8%. The TFEPI for coal deteriorates by 1.0%/year, which is mostly caused by a decrease in relative energy efficiency change. We define and identify 'innovators' who cause the frontier to shift. Most regions identified as frontier shifters are located outside of Japan's four major industrial areas.

## 1. Introduction

The first oil crisis hit the Japanese economy in 1973 and led to a drive for efficient energy use in Japan. As a result, Japan has achieved one of the highest levels of energy efficiency in the world. Energy conservation policy has been a crucial concern for Japan as a resource-poor country without a stable supply of energy. Moreover, Japan ratified the Kyoto protocol and must, by 2012, decrease its greenhouse gas emissions by 6% from its 1990 level. The Ministry of Environment (MOE) of Japan has proposed a carbon tax to mitigate carbon dioxide emissions since 2003. The proposed tax rate in 2003 was 3400 yen (approximately 29 US$ at the day's exchange rate) per ton of carbon contained in fossil fuel emissions, and, since 2004, it has been reduced to 2400 yen (approximately 22 US$ at the day's exchange rate). However, because of opposition from business interests, the MOE has failed to institute the carbon tax. Japan's carbon dioxide emissions from energy use have remained above the 1990 baseline and, in 2007, increased 15.0% above it. As Kasahara et al. (2007) suggested, a climate change tax combined with international emission trading might be a rational choice for Japan; however, in reality a climate change tax has been and will continue to be politically unacceptable. The Japanese government's plan depends on voluntary action to reduce energy use in industrial, commercial, and residential sectors, which seems to be unrealistic. In addition to Japan's obligation to implement the Kyoto mechanism including the international emission trading, improving energy efficiency or energy productivity *per se* has been the key issue for Japan's energy-environmental policy. However, the energy efficiency-enhancing policy may have two unintended consequences: First, improvements in energy efficiency may result in lower energy prices and in turn increased energy consumption. This is called the rebound effect which was first suggested by W.S. Jevons in 1865; however, this effect still remains debatable (recently, e.g., Hanley et al., 2009). Second, energy efficiency measures may not necessarily lead to reducing carbon emissions when Japan participates in international emissions trading schemes. In that case, the social cost of reducing carbon dioxide as well as the cap amount of carbon emissions will be different if Japan does not participate in these schemes.[1]

Two well-known indicators are commonly used to study whether energy inputs are efficiently used. The first is energy intensity, which measures the amount of energy consumption for economic output produced in the economy. According to this kind

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[1] Söderholm and Pettersson (2008) show that the social cost of power generation depends upon whether or not the country participates in international emissions trading in the Swedish case.

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of indicator, Japan is one of the world's leading countries in energy use. For example, if Japan's primary energy consumption (on a crude oil equivalent basis) per real GDP is taken as 1 in 2005, then that of the United States is 2.00, that of the United Kingdom is 1.35, that of France is 1.82, and that of Germany is 1.65.[2] For example, at the industry level, if energy consumption per unit of production in the Japanese iron and steel industry is taken as 1, that of the United States is 1.25, that of the United Kingdom is 1.22, and that of Germany is 1.17.[3] Moreover, if energy consumption per cement clinker in Japan is taken as 1, that of the United States is 1.77 and that of Western Europe is 1.30. The second indicator is energy efficiency (or energy productivity), defined as the economic output divided by the energy input (e.g., Berndt, 1990; Patterson, 1996; Han et al., 2007). Notice that although each indicator represents identical measures from different perspectives, we focus only on the application of energy efficiency and productivity in this paper.

The conventional energy efficiency index introduced in Patterson (1996) is partial-factor energy productivity because it disregards the substitution among energy consumption and other factors (e.g., labor and capital stock). If energy consumption is evaluated in terms of partial-factor energy productivity, the end result is a misleading estimate (Hu and Wang, 2006; Hu and Kao, 2007; Han et al., 2007; Honma and Hu, 2008). For this reason, even though of the above international comparisons, it does not follow that energy efficiency in Japan is higher than in other developed countries. For example, Hu and Kao (2007) show that Japan is not the best performer in the APEC economy in 1991–2000 using a total-factor framework.

This article evaluates the energy productivity change of regions in Japan with a total-factor framework. Under the traditional DEA-Malmquist index, one cannot evaluate the change in single-factor productivity under the total-factor framework. As a result, we use a new index, the total-factor energy productivity change index (TFEPI), which was proposed in Hu and Chang (2009). Following Hu and Chang (2009), we extend the work of Honma and Hu (2008) on total-factor energy efficiency (TFEE) to introduce a total-factor energy productivity index that integrates the concept of the total-factor energy efficiency index into the Malmquist productivity index (MPI). The MPI was first introduced by Caves et al. (1982) to measure total-factor productivity change by the ratio of the distance functions. Färe et al. (1994) broke down the MPI into efficiency change and technical change. They used data envelopment analysis (DEA), which is a nonparametric, linear programming method. To evaluate the TFEPI, we also use DEA. Moreover, we can decompose TFEPI into changes in relative energy efficiency (the catching up effect) and shifts in the technology of energy use (the innovation effect) under the total-factor framework. This study extends the panel dataset of Honma and Hu (2008) and analyzes prefecture-level data from 1993 to 2003. There are a single, aggregate output (real GDP) and 14 inputs in our DEA model, including 3 production factors (labor employment and real private and real public capital stocks), and 11 energy sources. To the best of our knowledge, no studies have attempted to assess changes in energy productivity for regions in Japan using a total-factor framework.[4] The revised energy conservation law evaluates energy efficiency with respect to each apparatus, factory, and building from April 2009. Our results shed new light on Japan's energy productivity changes by examining those changes by region and energy type.

The remainder of this paper is organized as follows: Section 2 introduces the proposed total-factor energy productivity index using the DEA approach. Section 3 interprets the data sources and describes the variables involved. Section 4 presents and discusses the empirical results in the case of Japan. Finally, Section 5 concludes the paper.

## 2. Total-factor energy productivity index

Hu and Chang (2009) propose the TFEPI, which combines the concepts of TFEE and MPI to investigate the energy productivity changes in regions of China. Because TFEE examines the optimal energy input level with the input-oriented constant returns to scale (CRS) DEA model, our TFEPI also follows an input-oriented model. Additionally, MPI, which is usually computed by an output-oriented DEA approach, is applied using an input-oriented framework in this study. In the following subsection, we first introduce the input-oriented MPI and proceed with TFEE. Finally, the TFEPI is presented with a discussion of how MPI and TFEE are integrated.

### 2.1. Input-oriented Malmquist productivity index

First, we assume that the production technology $\mathbf{S}^t$ models the transformation of multiple inputs, $\mathbf{x}^t \in R_+^K$, into multiple outputs, $\mathbf{y}^t \in R_+^M$, for each time period $t$, where

$$\mathbf{S}^t = \{(\mathbf{x}^t, \mathbf{y}^t) : \mathbf{x}^t \text{can produce } \mathbf{y}^t\} \tag{1}$$

The computation of input-oriented MPI relies on input-based distance functions. Following Färe et al. (1985) and Boussemart et al. (2003), the input distance function can be defined at $t$ as

$$D_i^t(\mathbf{x}^t, \mathbf{y}^t) = \sup\{\delta : (\mathbf{x}^t/\delta, \mathbf{y}^t) \in \mathbf{S}^t\} = (\inf\{\delta : (\delta\mathbf{x}^t, \mathbf{y}^t) \in \mathbf{S}^t\})^{-1} \tag{2}$$

where distance function (2) is based upon the reciprocal of the maximum proportional reduction of the input vector by a scalar $\delta$ to catch up to the production frontier. It is notable that $D_i{}^t(\mathbf{x}^t, \mathbf{y}^t) \geqslant 1$ and $D_i{}^t(\mathbf{x}^t, \mathbf{y}^t) = 1$ if and only if $(\mathbf{x}^t, \mathbf{y}^t)$ is on the production frontier. Therefore, input-oriented MPI can be measure as follows:

$$\begin{aligned} M_i(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) &= \left[\left(\frac{D_i^t(\mathbf{x}^t, \mathbf{y}^t)}{D_i^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}\right)\left(\frac{D_i^{t+1}(\mathbf{x}^t, \mathbf{y}^t)}{D_i^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}\right)\right]^{1/2} \\ &= \frac{D_i^t(\mathbf{x}^t, \mathbf{y}^t)}{D_i^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}\left[\left(\frac{D_i^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_i^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}\right)\left(\frac{D_i^{t+1}(\mathbf{x}^t, \mathbf{y}^t)}{D_i^t(\mathbf{x}^t, \mathbf{y}^t)}\right)\right]^{1/2} \end{aligned} \tag{3}$$

### 2.2. Total-factor energy efficiency

In order to pursue overall technical efficiency with energy inputs, our study adopts the CRS DEA model (Charnes et al., 1978). Let us first define some mathematical notations. There are $K$ inputs and $M$ outputs for each of $N$ objects. The $i$th object is represented by the column vectors $\mathbf{x}_i$ and $\mathbf{y}_i$, respectively. The $K \times N$ input matrix $\mathbf{X}$ and the $M \times N$ output matrix $\mathbf{Y}$ represent the data for all $N$ objects. The input-oriented CRS DEA model then solves the following linear programming problem for object $I$ in each year:

$$\begin{aligned} &\mathrm{Min}_{\theta,\lambda}\ \theta \\ &\text{s.t. } -\mathbf{y}_i + \mathbf{Y}\lambda \geqslant 0 \\ &\theta\mathbf{x}_i - \mathbf{X}\lambda \geqslant 0 \\ &\lambda \geqslant 0 \end{aligned} \tag{4}$$

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[2] The above figures are based on OECD (2007).

[3] Japan Business Federation (2008).

[4] On the productivity change of Japanese prefectures, Nemoto and Goto (2005) compute the total-factor productivity change for 1981–2000, and Miyara and Fukushige (2008) compute it for 1976–1997. However, these two models do not include energy as an input; their inputs are only capital stocks and labor.

**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 | 10843.73 | 13826.30 | 2009.20 | 88566.02 |
| Inputs | | | | | | |
| $x_1$ | Employed persons | Person | 1372095.79 | 1458692.35 | 313693.00 | 8782396.00 |
| $x_2$ | Private capital stock | Billion yen in 1995 prices | 22324.36 | 25983.45 | 3131.81 | 166007.50 |
| $x_3$ | Public capital stock | Billion yen in 1995 prices | 16435.11 | 13915.21 | 4005.28 | 83458.06 |
| $x_4$ | Electric power for residential use | Million kWh | 5067.27 | 4964.56 | 942.00 | 28428.00 |
| $x_5$ | Electric power for residential use | Million kWh | 11774.85 | 11079.22 | 1763.00 | 52955.00 |
| $x_6$ | Gasoline | kL | 1179741.78 | 1019686.72 | 268654.00 | 7591664.00 |
| $x_7$ | Kerosene | kL | 612685.61 | 654523.86 | 60428.00 | 4092522.00 |
| $x_8$ | Gas oil | kL | 896769.57 | 752560.76 | 140763.00 | 4807624.00 |
| $x_9$ | Heavy oil | kL | 1050366.68 | 950189.23 | 57223.00 | 5793805.00 |
| $x_{10}$ | City gas | Million MJ | 20480.33 | 40516.85 | 515.00 | 241405.00 |
| $x_{11}$ | Butane gas | Tons | 103035.14 | 130104.53 | 4914.00 | 770696.00 |
| $x_{12}$ | Propane gas | Tons | 211618.90 | 164136.00 | 39222.00 | 890332.00 |
| $x_{13}$ | Coal | 1000 tons | 368.72 | 573.48 | 4.87 | 2664.36 |
| $x_{14}$ | Coke | 1000 tons | 851.57 | 1621.14 | 0.47 | 7089.15 |

where $\theta$ is a scalar that represents the efficiency score for the $i$th object, with $0 \leqslant \theta \leqslant 1$. $\lambda$ is an $N \times 1$ vector of constants, and the weight vector $\lambda$ serves to form a convex combination of observed inputs and outputs.

After obtaining the efficiency score, we apply the approach of Ali and Seiford (1993) to compute the total slack, which includes radial and non-radial slacks. Hence, the TFEE index of region $i$ at time $t$ can be measured as

$$\begin{aligned}\mathrm{TFEE}_{it} &= \frac{\text{Target energy input}_{it}}{\text{Actual energy input}_{it}}\\ &= \frac{\text{Actual energy input}_{it} - \text{Total slack of energy input}_{it}}{\text{Actual energy input}_{it}} \qquad (5)\end{aligned}$$

## 2.3. Integrating MPI and TFEE to obtain TFEPI

In this section, we will show how TFEPI brings together MPI and TFEE. The four input-oriented distance functions in Eq. (3) can be replaced by the ratio of target energy input and actual energy input under technologies in different periods. For example, $D_i^t(\mathbf{x}^t, \mathbf{y}^t)$ would be presented as

$$\begin{aligned}(D_i^t(\mathbf{x}^t,\mathbf{y}^t))^{-1} &= \frac{\text{Target energy input under technology in } t}{\text{Actual energy input in } t}\\ &= \mathrm{TFEE}_t^t\\ (D_i^{t+1}(\mathbf{x}^t,\mathbf{y}^t))^{-1} &= \frac{\text{Target energy input under technology in } t+1}{\text{Actual energy input in } t}\\ &= \mathrm{TFEE}_t^{t+1}\\ (D_i^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1}))^{-1} &= \frac{\text{Target energy input under technology in } t+1}{\text{Actual energy input in } t+1}\\ &= \mathrm{TFEE}_{t+1}^{t+1}\\ (D_i^t(\mathbf{x}^{t+1},\mathbf{y}^{t+1}))^{-1} &= \frac{\text{Target energy input under technology in } t}{\text{Actual energy input in } t+1}\\ &= \mathrm{TFEE}_{t+1}^t \qquad (6)\end{aligned}$$

Therefore,

$$\mathrm{TFEPI} = \frac{\mathrm{TFEE}_{t+1}^{t+1}}{\mathrm{TFEE}_t^t}\left[\left(\frac{\mathrm{TFEE}_{t+1}^t}{\mathrm{TFEE}_{t+1}^{t+1}}\right)\left(\frac{\mathrm{TFEE}_t^t}{\mathrm{TFEE}_t^{t+1}}\right)\right]^{1/2} \qquad (7)$$

where the first ratio (outside the brackets) represents the total-factor energy efficiency changes and the second geometric product of the ratio captures the total-factor energy technical changes. Note that if the value of TFEPI or any of its components is less than unity, then a regression or deterioration in performance is indicated.

## 3. Description of data and variables

This study augments the panel dataset of Honma and Hu (2008) and analyzes data from 47 prefectures from 1993 to 2003. Table 1 presents the summary statistics of the inputs and output used in the DEA models. In our model, 3 production factors (labor employment, and real private and real public capital stocks) and 11 energy inputs (electric power for residential use, electric power for commercial and industrial use, gasoline, kerosene, heavy oil, light oil, city gas, butane gas, propane gas, coal, and coke) combine to make 14 inputs. These energy inputs are all used for final consumption in each region. The real regional GDP is the sole output. The data on private and public capital stocks are unavailable, and hence we extend the stock data estimated in Fukao and Yue (2000).[5]

Data on real prefectural GDP and labor (employed persons) are taken from the *Annual Report on Prefectural Accounts* (Cabinet Office, Government of Japan). Real GDP and real social and private capital stocks are adjusted to 1995 yen. We use the same data sources as Honma and Hu (2008): data on electric power are from the *Handbook of Electric Power Industry* (The Federation of Electric Power Companies of Japan); data on propane and butane gas consumption are taken from the website of the Japan LP Gas Association (http://www.j-lpgas.gr.jp/); data on city gas consumption are from the *Annual Statistics of Gas Industry* (Japan Gas Association); and data on gasoline, kerosene, light oil, and heavy oil are taken from the *Yearbook of Mineral Resources and Petroleum Products Statistics* (Ministry of Economy, Trade and Industry). Since there are no official statistics on coal and coke consumption by prefecture, they are taken from the estimated data in Kainou (2006).

Table 2 is a correlation matrix. As shown in the table, all inputs have positive correlation coefficients with the output, implying that all inputs satisfy the isotonicity property with the output for the DEA model.

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[5] Our extension methods of real public and private capital stocks are the same as Honma and Hu (2008).

**Table 2**
Correlation coefficients of input and output variables.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Real GDP | 1.00 | | | | | | | | | | | | | | |
| Employed persons | 0.99 | 1.00 | | | | | | | | | | | | | |
| Private capital stock | 0.99 | 0.98 | 1.00 | | | | | | | | | | | | |
| Public capital stock | 0.89 | 0.90 | 0.92 | 1.00 | | | | | | | | | | | |
| Electric power for residential use | 0.96 | 0.97 | 0.96 | 0.92 | 1.00 | | | | | | | | | | |
| Electric power for commercial and industrial use | 0.92 | 0.94 | 0.93 | 0.85 | 0.96 | 1.00 | | | | | | | | | |
| Gasoline | 0.90 | 0.92 | 0.92 | 0.88 | 0.96 | 0.95 | 1.00 | | | | | | | | |
| Kerosene | 0.67 | 0.70 | 0.67 | 0.85 | 0.69 | 0.62 | 0.71 | 1.00 | | | | | | | |
| Gas oil | 0.86 | 0.89 | 0.86 | 0.92 | 0.89 | 0.87 | 0.92 | 0.88 | 1.00 | | | | | | |
| Heavy oil | 0.80 | 0.81 | 0.80 | 0.82 | 0.77 | 0.78 | 0.81 | 0.77 | 0.89 | 1.00 | | | | | |
| City gas | 0.91 | 0.91 | 0.92 | 0.82 | 0.94 | 0.91 | 0.86 | 0.54 | 0.75 | 0.64 | 1.00 | | | | |
| Butane gas | 0.80 | 0.81 | 0.81 | 0.65 | 0.78 | 0.88 | 0.83 | 0.46 | 0.76 | 0.73 | 0.72 | 1.00 | | | |
| Propane gas | 0.79 | 0.82 | 0.79 | 0.78 | 0.87 | 0.87 | 0.92 | 0.67 | 0.86 | 0.75 | 0.70 | 0.77 | 1.00 | | |
| Coal | 0.16 | 0.19 | 0.21 | 0.30 | 0.27 | 0.29 | 0.32 | 0.20 | 0.33 | 0.29 | 0.18 | 0.26 | 0.36 | 1.00 | |
| Coke | 0.18 | 0.20 | 0.22 | 0.25 | 0.27 | 0.33 | 0.37 | 0.17 | 0.32 | 0.34 | 0.20 | 0.32 | 0.36 | 0.66 | 1.00 |

**Table 3**
Total-factor energy productivity index (TFEPI) for electric power for commercial and industrial use by region.

| ID | Region | Area | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 | 01/02 | 02/03 | Average | Cumulative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Hokkaido | A | 0.957 | 1.007 | 0.976 | 0.954 | 1.064 | 0.984 | 0.987 | 0.995 | 0.980 | 0.993 | 0.989 | 0.898 |
| 02 | Aomori | B | 0.999 | 1.004 | 0.978 | 1.000 | 0.972 | 0.984 | 0.965 | 0.989 | 0.940 | 0.976 | 0.981 | 0.823 |
| 03 | Iwate | B | 0.959 | 0.982 | 0.991 | 0.946 | 1.016 | 0.992 | 1.009 | 0.976 | 0.977 | 0.993 | 0.984 | 0.851 |
| 04 | Miyagi | B | 0.988 | 0.971 | 1.000 | 0.970 | 0.990 | 1.037 | 1.010 | 0.982 | 0.965 | 0.999 | 0.991 | 0.914 |
| 05 | Akita | B | 1.017 | 0.997 | 1.056 | 0.928 | 0.963 | 0.976 | 0.958 | 1.008 | 0.978 | 1.010 | 0.988 | 0.890 |
| 06 | Yamagata | B | 0.938 | 1.006 | 1.001 | 0.955 | 0.970 | 0.975 | 0.980 | 1.013 | 0.993 | 1.000 | 0.983 | 0.841 |
| 07 | Fukushima | B | 1.001 | 0.993 | 1.008 | 1.135 | 0.963 | 1.031 | 0.990 | 1.010 | 0.978 | 0.985 | 1.008 | 1.087 |
| 08 | Ibaraki | C | 0.944 | 0.958 | 0.967 | 0.615 | 1.516 | 0.900 | 0.919 | 0.812 | 1.065 | 0.999 | 0.947 | 0.582 |
| 09 | Tochigi | C | 0.911 | 1.009 | 0.982 | 0.985 | 1.136 | 0.972 | 1.010 | 1.004 | 1.003 | 1.048 | 1.005 | 1.048 |
| 10 | Gunma | C | 0.940 | 0.958 | 0.954 | 0.913 | 0.999 | 0.996 | 0.941 | 0.970 | 0.831 | 0.967 | 0.946 | 0.572 |
| 11 | Saitama | C | 0.933 | 0.957 | 0.994 | 0.727 | 1.275 | 0.982 | 1.029 | 1.013 | 0.987 | 1.055 | 0.987 | 0.876 |
| 12 | Chiba | C | 1.428 | 0.942 | 0.841 | 0.649 | 1.188 | 0.958 | 0.924 | 0.932 | 1.132 | 1.116 | 0.990 | 0.908 |
| 13 | Tokyo | C | 0.971 | 1.036 | 1.006 | 1.085 | 0.974 | 0.980 | 0.991 | 1.032 | 0.983 | 1.081 | 1.013 | 1.139 |
| 14 | Kanagawa | C | 0.618 | 0.953 | 0.970 | 1.123 | 0.863 | 1.043 | 1.022 | 0.990 | 1.148 | 1.203 | 0.979 | 0.807 |
| 15 | Niigata | D | 1.552 | 0.983 | 0.931 | 0.854 | 1.008 | 0.963 | 0.914 | 1.113 | 0.991 | 1.030 | 1.020 | 1.223 |
| 16 | Toyama | D | 0.937 | 1.020 | 1.029 | 0.945 | 0.968 | 0.941 | 0.927 | 0.909 | 0.933 | 1.011 | 0.961 | 0.673 |
| 17 | Ishikawa | D | 0.960 | 1.044 | 1.003 | 0.976 | 0.988 | 1.003 | 0.980 | 1.016 | 0.982 | 1.006 | 0.996 | 0.956 |
| 18 | Fukui | D | 0.956 | 1.016 | 1.019 | 0.979 | 1.025 | 0.968 | 0.952 | 1.006 | 0.978 | 1.004 | 0.990 | 0.904 |
| 19 | Yamanashi | D | 0.909 | 1.007 | 1.003 | 1.019 | 0.953 | 1.024 | 1.003 | 0.981 | 0.987 | 1.010 | 0.989 | 0.896 |
| 20 | Nagano | D | 0.968 | 1.021 | 1.011 | 0.937 | 1.015 | 0.986 | 1.005 | 1.009 | 0.960 | 1.006 | 0.991 | 0.917 |
| 21 | Gifu | D | 1.036 | 0.979 | 1.012 | 1.030 | 1.024 | 0.934 | 0.929 | 0.942 | 0.922 | 1.101 | 0.989 | 0.898 |
| 22 | Shizuoka | D | 0.915 | 0.964 | 0.994 | 0.627 | 1.320 | 0.879 | 0.867 | 0.899 | 0.964 | 1.011 | 0.930 | 0.484 |
| 23 | Aichi | D | 1.215 | 1.033 | 1.067 | 1.438 | 0.641 | 1.069 | 1.054 | 1.051 | 0.886 | 1.064 | 1.033 | 1.379 |
| 24 | Mie | E | 0.925 | 0.944 | 0.978 | 0.861 | 0.928 | 0.854 | 0.909 | 0.818 | 1.298 | 1.001 | 0.944 | 0.563 |
| 25 | Shiga | E | 0.975 | 1.011 | 0.960 | 0.924 | 0.734 | 0.907 | 0.895 | 0.855 | 0.942 | 0.990 | 0.916 | 0.415 |
| 26 | Kyoto | E | 0.848 | 0.986 | 0.955 | 0.974 | 1.204 | 1.025 | 1.043 | 1.035 | 0.961 | 1.040 | 1.003 | 1.034 |
| 27 | Osaka | E | 1.186 | 1.022 | 1.008 | 0.870 | 1.036 | 0.933 | 1.055 | 0.960 | 0.923 | 0.913 | 0.987 | 0.877 |
| 28 | Hyogo | E | 5.556 | 1.024 | 0.773 | 0.883 | 1.072 | 0.934 | 1.084 | 0.936 | 0.919 | 1.079 | 1.146 | 3.908 |
| 29 | Nara | E | 0.965 | 1.055 | 1.012 | 0.979 | 0.968 | 1.005 | 0.999 | 1.018 | 1.007 | 1.009 | 1.001 | 1.013 |
| 30 | Wakayama | E | 1.994 | 1.014 | 1.005 | 0.991 | 0.865 | 0.868 | 0.816 | 0.946 | 0.931 | 0.978 | 1.006 | 1.062 |
| 31 | Tottori | F | 1.020 | 1.079 | 0.965 | 0.925 | 0.991 | 1.013 | 0.973 | 1.002 | 0.944 | 0.996 | 0.990 | 0.903 |
| 32 | Shimane | F | 0.943 | 0.992 | 0.997 | 0.967 | 1.087 | 0.970 | 0.961 | 1.063 | 0.938 | 0.984 | 0.989 | 0.897 |
| 33 | Okayama | F | 0.971 | 1.123 | 1.021 | 1.002 | 0.989 | 0.962 | 0.986 | 0.996 | 1.025 | 0.841 | 0.989 | 0.898 |
| 34 | Hiroshima | F | 0.981 | 1.001 | 1.005 | 0.998 | 0.961 | 0.959 | 1.026 | 0.991 | 0.940 | 1.037 | 0.989 | 0.898 |
| 35 | Yamaguchi | F | 2.880 | 1.032 | 1.048 | 1.144 | 0.968 | 0.906 | 1.099 | 1.006 | 1.026 | 0.975 | 1.132 | 3.453 |
| 36 | Tokushima | G | 0.944 | 1.012 | 0.939 | 0.980 | 0.959 | 0.962 | 0.993 | 1.005 | 0.978 | 1.008 | 0.978 | 0.797 |
| 37 | Kagawa | G | 0.969 | 1.020 | 0.980 | 0.938 | 0.996 | 0.951 | 0.966 | 1.000 | 0.994 | 0.999 | 0.981 | 0.827 |
| 38 | Ehime | G | 1.006 | 0.985 | 0.952 | 0.925 | 0.981 | 0.963 | 0.996 | 0.999 | 0.971 | 1.019 | 0.979 | 0.812 |
| 39 | Kochi | G | 0.989 | 1.011 | 0.971 | 1.006 | 0.994 | 1.029 | 1.008 | 0.961 | 0.981 | 0.996 | 0.994 | 0.944 |
| 40 | Fukuoka | H | 3.092 | 0.969 | 0.995 | 1.019 | 0.961 | 0.953 | 1.002 | 0.988 | 0.976 | 1.023 | 1.106 | 2.749 |
| 41 | Saga | H | 0.974 | 0.997 | 0.947 | 1.004 | 0.927 | 1.006 | 0.972 | 0.958 | 0.977 | 1.013 | 0.977 | 0.794 |
| 42 | Nagasaki | H | 1.086 | 1.105 | 0.980 | 0.970 | 1.060 | 0.967 | 0.990 | 0.980 | 0.999 | 1.031 | 1.016 | 1.168 |
| 43 | Kumamoto | H | 0.983 | 0.981 | 0.976 | 0.940 | 0.949 | 1.012 | 1.036 | 0.991 | 0.967 | 1.035 | 0.987 | 0.873 |
| 44 | Oita | H | 0.986 | 0.990 | 1.016 | 1.024 | 1.000 | 0.978 | 1.050 | 0.982 | 1.011 | 1.009 | 1.004 | 1.045 |
| 45 | Miyazaki | H | 1.026 | 1.168 | 0.987 | 0.914 | 1.002 | 1.019 | 0.980 | 0.972 | 1.005 | 0.965 | 1.002 | 1.019 |
| 46 | Kagoshima | H | 0.946 | 0.978 | 0.942 | 0.947 | 0.948 | 1.003 | 1.050 | 0.993 | 0.955 | 0.993 | 0.975 | 0.776 |
| 47 | Okinawa | H | 0.971 | 0.980 | 0.988 | 0.983 | 0.952 | 1.024 | 1.012 | 0.972 | 1.001 | 0.953 | 0.983 | 0.846 |
| | Summary | | 1.088 | 1.006 | 0.982 | 0.947 | 0.999 | 0.973 | 0.983 | 0.979 | 0.981 | 1.011 | 0.994 | 0.944 |

*Note*: A (Hokkaido), B (Tohoku), C (Kanto), D (Chubu), E (Kinki), F (Chugoku), G (Shikoku), and H (Kyushu).

**Table 4**
Total-factor energy productivity index (TFEPI) for kerosene by region.

| ID | Region | Area | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 | 01/02 | 02/03 | Average | Cumulative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Hokkaido | A | 1.116 | 0.999 | 0.982 | 0.435 | 2.202 | 1.001 | 0.965 | 1.093 | 0.957 | 1.020 | 1.008 | 1.082 |
| 02 | Aomori | B | 0.944 | 0.768 | 1.437 | 0.900 | 1.475 | 0.912 | 1.453 | 0.795 | 0.796 | 0.954 | 1.010 | 1.106 |
| 03 | Iwate | B | 0.950 | 0.930 | 1.044 | 1.024 | 0.995 | 0.994 | 0.945 | 0.910 | 0.750 | 1.138 | 0.963 | 0.686 |
| 04 | Miyagi | B | 1.112 | 1.003 | 1.026 | 1.291 | 1.065 | 0.914 | 0.947 | 1.134 | 0.891 | 1.014 | 1.034 | 1.397 |
| 05 | Akita | B | 0.962 | 0.956 | 1.051 | 1.291 | 0.835 | 0.990 | 0.918 | 1.076 | 0.898 | 0.918 | 0.983 | 0.839 |
| 06 | Yamagata | B | 1.032 | 0.945 | 1.066 | 0.889 | 0.978 | 1.044 | 0.945 | 1.056 | 0.977 | 1.066 | 0.998 | 0.982 |
| 07 | Fukushima | B | 1.059 | 0.963 | 1.052 | 0.903 | 1.311 | 1.051 | 1.080 | 1.030 | 0.956 | 1.054 | 1.041 | 1.495 |
| 08 | Ibaraki | C | 1.058 | 0.991 | 1.013 | 0.538 | 1.474 | 0.964 | 0.978 | 0.980 | 0.943 | 1.004 | 0.970 | 0.738 |
| 09 | Tochigi | C | 0.998 | 0.976 | 1.035 | 1.000 | 1.271 | 1.009 | 1.035 | 1.083 | 0.929 | 1.070 | 1.037 | 1.440 |
| 10 | Gunma | C | 1.043 | 0.970 | 1.029 | 1.021 | 0.998 | 0.949 | 0.978 | 1.005 | 0.966 | 1.058 | 1.001 | 1.011 |
| 11 | Saitama | C | 1.085 | 0.912 | 1.073 | 0.758 | 1.120 | 0.951 | 1.027 | 1.098 | 0.898 | 1.169 | 1.001 | 1.014 |
| 12 | Chiba | C | 0.998 | 0.820 | 0.897 | 0.638 | 0.998 | 0.979 | 1.021 | 1.258 | 1.117 | 1.050 | 0.963 | 0.689 |
| 13 | Tokyo | C | 1.214 | 1.122 | 1.043 | 2.065 | 0.404 | 1.028 | 0.938 | 0.846 | 0.881 | 0.986 | 0.983 | 0.839 |
| 14 | Kanagawa | C | 0.823 | 0.908 | 1.042 | 1.415 | 0.830 | 0.836 | 0.994 | 0.932 | 1.021 | 0.812 | 0.948 | 0.587 |
| 15 | Niigata | D | 1.032 | 0.944 | 0.950 | 0.892 | 1.090 | 0.889 | 0.979 | 1.361 | 0.865 | 1.124 | 1.004 | 1.038 |
| 16 | Toyama | D | 1.011 | 0.965 | 1.080 | 0.985 | 1.118 | 0.979 | 0.966 | 0.950 | 0.950 | 1.126 | 1.011 | 1.115 |
| 17 | Ishikawa | D | 0.922 | 0.815 | 0.964 | 1.380 | 0.984 | 1.014 | 0.897 | 1.048 | 0.953 | 1.125 | 1.000 | 1.003 |
| 18 | Fukui | D | 1.044 | 0.905 | 1.063 | 1.106 | 1.112 | 1.007 | 1.052 | 0.969 | 0.952 | 1.076 | 1.027 | 1.301 |
| 19 | Yamanashi | D | 1.013 | 0.916 | 1.019 | 1.040 | 0.954 | 0.997 | 1.003 | 1.006 | 1.023 | 1.076 | 1.004 | 1.039 |
| 20 | Nagano | D | 1.090 | 0.962 | 1.037 | 0.986 | 0.958 | 0.981 | 1.050 | 0.957 | 0.878 | 1.136 | 1.001 | 1.011 |
| 21 | Gifu | D | 0.971 | 0.970 | 0.990 | 1.156 | 1.185 | 0.980 | 0.991 | 0.996 | 0.963 | 1.073 | 1.025 | 1.275 |
| 22 | Shizuoka | D | 1.061 | 0.985 | 1.039 | 0.643 | 1.240 | 0.998 | 1.058 | 0.991 | 0.962 | 1.048 | 0.991 | 0.913 |
| 23 | Aichi | D | 1.115 | 0.953 | 1.198 | 1.898 | 0.661 | 1.015 | 1.016 | 0.978 | 0.931 | 1.060 | 1.047 | 1.590 |
| 24 | Mie | E | 1.055 | 1.007 | 0.966 | 0.929 | 1.161 | 0.971 | 1.062 | 0.950 | 0.985 | 0.977 | 1.004 | 1.045 |
| 25 | Shiga | E | 1.043 | 0.900 | 0.976 | 1.014 | 0.949 | 0.883 | 0.955 | 0.928 | 0.966 | 1.028 | 0.963 | 0.685 |
| 26 | Kyoto | E | 1.106 | 0.936 | 1.019 | 1.151 | 0.998 | 1.011 | 1.075 | 1.033 | 0.960 | 1.276 | 1.052 | 1.667 |
| 27 | Osaka | E | 1.138 | 1.012 | 1.057 | 0.973 | 0.941 | 0.925 | 0.993 | 0.974 | 0.987 | 1.066 | 1.005 | 1.050 |
| 28 | Hyogo | E | 1.058 | 0.928 | 0.756 | 1.109 | 1.048 | 1.021 | 1.079 | 0.934 | 0.985 | 1.037 | 0.990 | 0.906 |
| 29 | Nara | E | 1.082 | 0.948 | 1.110 | 1.101 | 1.264 | 1.041 | 1.073 | 0.976 | 0.991 | 1.313 | 1.084 | 2.248 |
| 30 | Wakayama | E | 1.042 | 0.953 | 1.068 | 1.112 | 0.907 | 0.773 | 0.998 | 0.976 | 0.942 | 1.163 | 0.988 | 0.882 |
| 31 | Tottori | F | 0.950 | 0.835 | 1.084 | 1.003 | 0.986 | 1.120 | 1.120 | 1.052 | 0.997 | 0.984 | 1.010 | 1.101 |
| 32 | Shimane | F | 1.082 | 0.918 | 1.038 | 1.081 | 1.060 | 0.930 | 1.075 | 1.094 | 0.878 | 1.057 | 1.018 | 1.199 |
| 33 | Okayama | F | 0.995 | 0.988 | 1.009 | 1.001 | 1.019 | 1.010 | 0.974 | 1.011 | 0.963 | 1.004 | 0.997 | 0.974 |
| 34 | Hiroshima | F | 0.981 | 1.001 | 1.005 | 0.998 | 0.961 | 0.974 | 1.026 | 0.991 | 0.949 | 1.045 | 0.993 | 0.928 |
| 35 | Yamaguchi | F | 1.018 | 0.988 | 0.987 | 1.030 | 1.016 | 0.760 | 1.106 | 1.025 | 0.993 | 1.009 | 0.989 | 0.896 |
| 36 | Tokushima | G | 1.082 | 1.006 | 1.023 | 0.947 | 1.084 | 0.993 | 1.082 | 1.112 | 0.952 | 1.138 | 1.040 | 1.481 |
| 37 | Kagawa | G | 1.026 | 0.982 | 0.999 | 1.051 | 1.027 | 0.943 | 0.994 | 1.018 | 0.968 | 0.999 | 1.000 | 1.003 |
| 38 | Ehime | G | 1.070 | 0.937 | 1.127 | 1.022 | 0.984 | 0.890 | 1.058 | 0.994 | 0.948 | 1.094 | 1.010 | 1.102 |
| 39 | Kochi | G | 1.052 | 0.915 | 1.055 | 0.993 | 1.093 | 0.934 | 1.035 | 1.006 | 0.964 | 1.222 | 1.024 | 1.263 |
| 40 | Fukuoka | H | 1.057 | 0.969 | 0.995 | 1.019 | 0.961 | 0.953 | 1.002 | 0.988 | 0.976 | 1.023 | 0.994 | 0.939 |
| 41 | Saga | H | 1.020 | 0.979 | 0.999 | 1.079 | 1.201 | 1.032 | 1.079 | 1.036 | 0.970 | 1.066 | 1.044 | 1.541 |
| 42 | Nagasaki | H | 1.177 | 0.991 | 0.994 | 1.018 | 1.132 | 0.951 | 0.990 | 0.980 | 0.999 | 1.032 | 1.024 | 1.270 |
| 43 | Kumamoto | H | 1.067 | 0.910 | 1.027 | 1.002 | 1.025 | 0.984 | 1.096 | 1.083 | 0.958 | 1.111 | 1.024 | 1.272 |
| 44 | Oita | H | 0.986 | 0.957 | 1.016 | 1.024 | 1.012 | 0.910 | 1.050 | 0.990 | 1.010 | 1.021 | 0.997 | 0.969 |
| 45 | Miyazaki | H | 1.067 | 0.983 | 1.012 | 1.027 | 1.027 | 1.013 | 0.972 | 1.020 | 1.013 | 1.139 | 1.026 | 1.297 |
| 46 | Kagoshima | H | 1.099 | 1.000 | 1.010 | 0.980 | 1.005 | 0.957 | 1.080 | 1.002 | 0.950 | 1.037 | 1.011 | 1.114 |
| 47 | Okinawa | H | 1.157 | 1.457 | 0.883 | 1.204 | 0.980 | 1.027 | 1.150 | 0.976 | 1.107 | 1.067 | 1.091 | 2.391 |
|  | Summary |  | 1.042 | 0.957 | 1.025 | 1.013 | 1.041 | 0.965 | 1.026 | 1.011 | 0.953 | 1.062 | 1.009 | 1.091 |

*Note*: A (Hokkaido), B (Tohoku), C (Kanto), D (Chubu), E (Kinki), F (Chugoku), G (Shikoku), and H (Kyushu).

## 4. Results

### 4.1. Total-factor energy productivity change in Japan

We calculated the total-factor energy productivity changes of the four major types of energy: electric power for commercial and industrial use, kerosene, heavy oil, and coal.[6] Tables 3–6 present the total-factor energy productivity changes of regions in Japan for 1993–2003. From our findings, the average annual net total-factor energy productivity changes of electrical power for commercial and industrial use, kerosene, heavy oil, and coal for the period from 1993 to 2003 were −0.6%, 0.9%, 0.1%, and −1.0%, respectively. The TFEPIs of all these four energy sources deteriorate in periods of 1998–1999 and 2001–2002, respectively. The other years exhibit both improved and deteriorated TFEPIs. The TFEPIs for each energy source generally remained largely unchanged in these 11 years.

Now we consider the trends of consumption amount and TFEPI changes of each energy source during the sample period. If consumption of each form of energy in 1993 is taken as 1, that of electrical power for commercial and industrial use in 2003 is 1.166, that of kerosene is 0.998, that of heavy oil is 0.960, and that of coal is 1.025. The forms of energy for which the TFEPI deteriorates in the sample period have experienced increases in consumption, whereas consumption has decreased for energy sources with improved TFEPI.

By energy conservation law, large companies in Japan should report their aggregated energy consumption on a crude oil equivalent basis to the government and implement energy conservation measures. However, our results indicate differences

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[6] There are 11 energy inputs in our model; however, we analyze four major energy sources within them.

**Table 5**
Total-factor energy productivity index (TFEPI) for heavy oil by region.

| ID | Region | Area | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 | 01/02 | 02/03 | Average | Cumulative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Hokkaido | A | 0.977 | 0.983 | 0.932 | 0.522 | 1.837 | 0.962 | 1.084 | 0.979 | 0.982 | 0.933 | 0.978 | 0.802 |
| 02 | Aomori | B | 0.956 | 1.088 | 0.965 | 0.972 | 1.093 | 1.034 | 1.121 | 1.071 | 0.950 | 0.990 | 1.022 | 1.245 |
| 03 | Iwate | B | 1.128 | 1.056 | 0.962 | 0.982 | 1.070 | 0.935 | 0.960 | 1.021 | 1.159 | 1.176 | 1.042 | 1.508 |
| 04 | Miyagi | B | 1.042 | 0.955 | 0.982 | 1.072 | 1.059 | 1.068 | 0.829 | 1.052 | 1.051 | 1.024 | 1.011 | 1.113 |
| 05 | Akita | B | 1.115 | 0.799 | 1.035 | 0.941 | 1.109 | 1.146 | 0.887 | 0.884 | 0.969 | 1.219 | 1.002 | 1.021 |
| 06 | Yamagata | B | 1.010 | 1.012 | 0.964 | 1.101 | 1.277 | 0.903 | 0.935 | 0.935 | 0.957 | 1.018 | 1.006 | 1.064 |
| 07 | Fukushima | B | 0.924 | 1.029 | 1.187 | 0.827 | 1.404 | 0.838 | 0.861 | 0.877 | 1.069 | 0.953 | 0.983 | 0.844 |
| 08 | Ibaraki | C | 1.063 | 1.130 | 0.772 | 0.506 | 1.632 | 0.859 | 0.779 | 0.735 | 0.753 | 0.844 | 0.867 | 0.239 |
| 09 | Tochigi | C | 0.974 | 0.999 | 1.009 | 1.021 | 1.081 | 0.997 | 1.048 | 1.033 | 0.958 | 0.963 | 1.007 | 1.077 |
| 10 | Gunma | C | 0.982 | 0.961 | 0.965 | 0.966 | 1.042 | 0.987 | 1.000 | 0.986 | 0.891 | 0.995 | 0.977 | 0.791 |
| 11 | Saitama | C | 1.021 | 1.005 | 1.059 | 1.225 | 0.871 | 1.004 | 1.015 | 1.034 | 1.004 | 0.988 | 1.019 | 1.213 |
| 12 | Chiba | C | 1.009 | 1.134 | 1.071 | 0.970 | 0.832 | 1.088 | 1.060 | 1.266 | 0.962 | 0.861 | 1.018 | 1.195 |
| 13 | Tokyo | C | 1.192 | 1.109 | 1.060 | 1.515 | 0.695 | 0.975 | 1.014 | 0.960 | 0.895 | 1.001 | 1.023 | 1.256 |
| 14 | Kanagawa | C | 0.931 | 1.081 | 1.109 | 1.214 | 0.662 | 1.230 | 1.033 | 0.971 | 1.039 | 1.214 | 1.034 | 1.396 |
| 15 | Niigata | D | 0.973 | 0.996 | 0.970 | 0.989 | 0.973 | 1.065 | 1.008 | 0.972 | 0.964 | 1.055 | 0.996 | 0.959 |
| 16 | Toyama | D | 0.927 | 1.053 | 1.079 | 1.002 | 0.959 | 1.001 | 0.818 | 0.963 | 1.008 | 0.940 | 0.973 | 0.757 |
| 17 | Ishikawa | D | 0.856 | 0.792 | 1.013 | 1.082 | 1.234 | 1.008 | 1.019 | 0.977 | 0.925 | 1.112 | 0.994 | 0.946 |
| 18 | Fukui | D | 0.899 | 1.007 | 1.021 | 1.119 | 1.130 | 0.834 | 1.169 | 1.098 | 0.970 | 1.017 | 1.021 | 1.234 |
| 19 | Yamanashi | D | 1.169 | 1.042 | 0.990 | 0.910 | 1.281 | 1.011 | 1.023 | 0.979 | 1.022 | 0.994 | 1.038 | 1.448 |
| 20 | Nagano | D | 1.018 | 0.990 | 1.028 | 0.993 | 1.059 | 0.978 | 0.990 | 0.974 | 0.947 | 1.003 | 0.998 | 0.977 |
| 21 | Gifu | D | 0.971 | 0.970 | 0.990 | 1.106 | 1.004 | 0.980 | 0.991 | 0.996 | 0.963 | 1.066 | 1.003 | 1.028 |
| 22 | Shizuoka | D | 0.903 | 0.905 | 1.009 | 0.542 | 1.504 | 0.810 | 0.823 | 0.935 | 0.974 | 1.002 | 0.915 | 0.409 |
| 23 | Aichi | D | 1.128 | 0.994 | 1.114 | 1.629 | 0.667 | 1.037 | 0.990 | 0.991 | 0.910 | 0.999 | 1.023 | 1.255 |
| 24 | Mie | E | 0.917 | 0.917 | 1.020 | 0.844 | 1.522 | 0.694 | 1.027 | 0.741 | 1.356 | 0.847 | 0.960 | 0.668 |
| 25 | Shiga | E | 0.957 | 1.007 | 1.018 | 0.940 | 0.769 | 1.005 | 1.072 | 1.066 | 0.966 | 0.947 | 0.971 | 0.746 |
| 26 | Kyoto | E | 1.117 | 0.977 | 1.090 | 1.051 | 1.110 | 1.004 | 1.088 | 1.094 | 1.142 | 1.090 | 1.075 | 2.066 |
| 27 | Osaka | E | 1.009 | 1.029 | 1.065 | 0.999 | 0.971 | 0.954 | 1.012 | 0.960 | 0.825 | 0.892 | 0.969 | 0.732 |
| 28 | Hyogo | E | 1.071 | 1.052 | 0.937 | 1.045 | 1.052 | 0.963 | 1.007 | 0.944 | 0.987 | 1.030 | 1.008 | 1.080 |
| 29 | Nara | E | 1.370 | 1.120 | 1.119 | 1.092 | 1.207 | 1.085 | 1.026 | 0.962 | 1.059 | 1.045 | 1.104 | 2.684 |
| 30 | Wakayama | E | 0.889 | 0.987 | 0.857 | 1.364 | 0.787 | 0.778 | 1.149 | 0.920 | 1.157 | 0.831 | 0.956 | 0.639 |
| 31 | Tottori | F | 1.136 | 0.922 | 1.015 | 0.986 | 0.957 | 1.081 | 0.924 | 1.019 | 0.888 | 1.118 | 1.001 | 1.015 |
| 32 | Shimane | F | 0.977 | 0.958 | 1.075 | 1.060 | 1.236 | 1.024 | 1.061 | 0.986 | 0.911 | 1.024 | 1.028 | 1.317 |
| 33 | Okayama | F | 0.934 | 0.965 | 1.079 | 1.001 | 1.019 | 0.914 | 0.915 | 1.025 | 1.212 | 0.935 | 0.996 | 0.964 |
| 34 | Hiroshima | F | 0.905 | 1.001 | 1.005 | 0.959 | 1.035 | 0.999 | 1.092 | 0.991 | 0.970 | 0.938 | 0.988 | 0.887 |
| 35 | Yamaguchi | F | 0.951 | 0.895 | 0.889 | 0.861 | 1.014 | 1.035 | 0.776 | 1.080 | 0.971 | 1.114 | 0.953 | 0.620 |
| 36 | Tokushima | G | 0.808 | 0.934 | 1.142 | 1.151 | 1.253 | 0.864 | 1.006 | 0.967 | 0.917 | 1.262 | 1.019 | 1.208 |
| 37 | Kagawa | G | 1.003 | 0.938 | 0.999 | 0.996 | 1.059 | 0.943 | 0.994 | 1.041 | 1.150 | 0.930 | 1.003 | 1.035 |
| 38 | Ehime | G | 0.933 | 1.018 | 0.773 | 1.025 | 1.049 | 1.060 | 1.057 | 1.096 | 1.089 | 1.007 | 1.006 | 1.064 |
| 39 | Kochi | G | 1.088 | 1.023 | 0.941 | 1.074 | 1.079 | 0.932 | 1.112 | 0.971 | 1.051 | 1.063 | 1.032 | 1.366 |
| 40 | Fukuoka | H | 1.008 | 0.969 | 0.995 | 1.019 | 0.987 | 0.953 | 1.002 | 0.969 | 1.023 | 1.004 | 0.993 | 0.929 |
| 41 | Saga | H | 1.108 | 0.921 | 0.992 | 1.094 | 1.294 | 1.000 | 1.064 | 1.036 | 1.111 | 0.906 | 1.048 | 1.592 |
| 42 | Nagasaki | H | 0.825 | 0.853 | 0.945 | 1.137 | 1.033 | 1.236 | 0.959 | 1.052 | 0.816 | 0.896 | 0.966 | 0.711 |
| 43 | Kumamoto | H | 1.089 | 0.894 | 1.064 | 1.024 | 1.074 | 0.997 | 1.223 | 1.084 | 0.940 | 1.009 | 1.036 | 1.430 |
| 44 | Oita | H | 0.776 | 0.990 | 0.943 | 1.024 | 1.047 | 0.923 | 1.117 | 1.044 | 1.035 | 0.942 | 0.980 | 0.814 |
| 45 | Miyazaki | H | 1.106 | 0.852 | 1.012 | 1.027 | 1.108 | 0.965 | 1.052 | 1.095 | 1.010 | 1.002 | 1.020 | 1.220 |
| 46 | Kagoshima | H | 1.071 | 0.977 | 0.987 | 1.058 | 1.037 | 0.976 | 0.770 | 1.030 | 1.023 | 0.980 | 0.987 | 0.880 |
| 47 | Okinawa | H | 1.151 | 1.191 | 0.666 | 1.547 | 0.967 | 0.978 | 1.271 | 0.897 | 0.952 | 0.957 | 1.033 | 1.386 |
|  | Summary |  | 1.002 | 0.986 | 0.993 | 1.011 | 1.065 | 0.976 | 0.999 | 0.991 | 0.992 | 0.999 | 1.001 | 1.011 |

*Note*: A (Hokkaido), B (Tohoku), C (Kanto), D (Chubu), E (Kinki), F (Chugoku), G (Shikoku), and H (Kyushu).

in energy productivity changes between energy sources, which tend to be disregarded in energy policy. The policy implications flowing from the results are that the former type of energy should be improved or replaced by the latter since each energy source is substitutable. From the available statistics, we know only that partial-factor energy efficiency, i.e., the change of GDP per unit of final energy consumption (heating value), in Japan only increased 0.1% annually during the sample period.[7] Since the existing formal energy productivity indices in Japan are based on the aggregated energy consumption in the partial-factor framework, our results shed light on the total-factor productivity of individual sources of energy.

At the regional level, only four (Tochigi, Aichi, Nara, and Miyazaki) of the 47 regions enhanced their total-factor energy productivities for all four kinds of energy during the sample period, whereas two regions (Ibaraki and Shizuoka) showed deterioration in all categories. The best and the worst performers in the average TFEPI of the four energy sources are as follows. For electric power for commercial and industrial use, while the TFEPI in Hyogo increased 14.6% annually during 1993–2003, in Shiga it declined 8.4%/year. For kerosene, the TFEPI in Okinawa increased 9.1%, whereas in Kanagawa it declined 5.2%. For heavy oil, the TFEPI in Nara increased by 10.4%, and in Ibaraki it declined 13.3%. For coal, the TFEPI in Miyazaki increased 23.1%, while in Kanagawa it declined 30.1%.[8] It is possible that an improvement in energy productivity in a region may be attributable to the changing industrial structure in that region. We regard a prefecture as a

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[7] This number is calculated by Japan's *Energy White Paper 2007* (Ministry of Economy, Trade and Industry, 2007).

[8] Some coal scores have extreme values because of the unstable results of technical changes.

**Table 6**
Total-factor energy productivity index (TFEPI) for coal by region.

| ID | Region | Area | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 | 01/02 | 02/03 | Average | Cumulative |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | Hokkaido | A | 0.787 | 0.962 | 1.032 | 0.499 | 2.161 | 1.111 | 0.951 | 1.158 | 0.919 | 0.931 | 0.987 | 0.881 |
| 02 | Aomori | B | 0.851 | 0.759 | 1.413 | 0.653 | 2.232 | 0.885 | 1.548 | 0.539 | 0.866 | 0.892 | 0.973 | 0.758 |
| 03 | Iwate | B | 0.868 | 0.676 | 0.921 | 1.519 | 1.096 | 1.050 | 0.997 | 0.849 | 0.523 | 0.994 | 0.916 | 0.415 |
| 04 | Miyagi | B | 0.978 | 0.971 | 0.982 | 0.991 | 0.958 | 1.000 | 1.000 | 0.981 | 0.952 | 1.006 | 0.982 | 0.832 |
| 05 | Akita | B | 1.070 | 0.938 | 0.990 | 0.914 | 1.205 | 0.914 | 0.967 | 0.956 | 1.014 | 0.985 | 0.992 | 0.923 |
| 06 | Yamagata | B | 0.989 | 0.974 | 1.090 | 1.010 | 1.206 | 0.931 | 0.911 | 0.911 | 1.080 | 1.035 | 1.010 | 1.104 |
| 07 | Fukushima | B | 0.955 | 1.008 | 1.038 | 1.008 | 1.076 | 0.763 | 0.549 | 1.204 | 1.133 | 1.000 | 0.953 | 0.620 |
| 08 | Ibaraki | C | 1.061 | 1.084 | 0.818 | 0.175 | 3.871 | 0.741 | 0.640 | 0.554 | 0.684 | 0.938 | 0.800 | 0.108 |
| 09 | Tochigi | C | 0.934 | 1.070 | 0.997 | 1.197 | 0.990 | 0.885 | 0.921 | 0.929 | 1.139 | 1.100 | 1.012 | 1.123 |
| 10 | Gunma | C | 0.985 | 1.008 | 0.965 | 0.984 | 0.983 | 0.992 | 0.980 | 0.960 | 0.948 | 0.987 | 0.979 | 0.809 |
| 11 | Saitama | C | 0.849 | 0.781 | 0.823 | 0.227 | 4.558 | 1.174 | 1.108 | 1.018 | 0.873 | 1.189 | 0.975 | 0.777 |
| 12 | Chiba | C | 0.806 | 0.613 | 0.431 | 0.251 | 3.134 | 0.815 | 0.826 | 0.722 | 0.411 | 1.228 | 0.727 | 0.041 |
| 13 | Tokyo | C | 1.121 | 1.071 | 0.970 | 2.949 | 0.322 | 0.992 | 1.022 | 0.978 | 0.929 | 1.047 | 1.006 | 1.066 |
| 14 | Kanagawa | C | 0.671 | 0.383 | 0.289 | 2.844 | 0.341 | 0.412 | 0.631 | 0.689 | 1.640 | 1.314 | 0.699 | 0.028 |
| 15 | Niigata | D | 0.774 | 0.888 | 0.787 | 0.475 | 2.149 | 0.987 | 0.552 | 0.420 | 1.032 | 1.199 | 0.831 | 0.157 |
| 16 | Toyama | D | 0.969 | 0.980 | 0.990 | 1.144 | 0.867 | 0.994 | 1.019 | 1.003 | 1.020 | 1.061 | 1.002 | 1.023 |
| 17 | Ishikawa | D | 1.079 | 1.124 | 1.003 | 0.888 | 1.344 | 1.013 | 0.988 | 0.993 | 0.967 | 0.998 | 1.034 | 1.391 |
| 18 | Fukui | D | 1.188 | 1.130 | 1.051 | 1.099 | 1.133 | 1.138 | 1.341 | 0.949 | 1.111 | 1.052 | 1.115 | 2.972 |
| 19 | Yamanashi | D | 1.140 | 1.042 | 0.997 | 0.910 | 1.253 | 1.048 | 0.981 | 0.889 | 1.022 | 1.109 | 1.034 | 1.398 |
| 20 | Nagano | D | 1.021 | 0.997 | 1.008 | 0.963 | 1.220 | 1.047 | 1.103 | 0.982 | 0.945 | 1.070 | 1.033 | 1.381 |
| 21 | Gifu | D | 0.892 | 1.293 | 0.827 | 1.242 | 0.976 | 0.849 | 0.768 | 0.544 | 0.896 | 1.687 | 0.953 | 0.619 |
| 22 | Shizuoka | D | 1.031 | 0.985 | 0.976 | 0.887 | 1.091 | 0.998 | 1.052 | 0.954 | 0.986 | 1.011 | 0.996 | 0.958 |
| 23 | Aichi | D | 1.192 | 0.975 | 1.259 | 5.479 | 0.323 | 1.671 | 1.102 | 0.942 | 0.710 | 0.974 | 1.120 | 3.103 |
| 24 | Mie | E | 0.981 | 1.007 | 0.923 | 1.257 | 0.397 | 1.790 | 1.018 | 1.380 | 1.329 | 0.893 | 1.031 | 1.358 |
| 25 | Shiga | E | 1.161 | 1.179 | 1.212 | 1.056 | 0.853 | 1.493 | 1.064 | 0.609 | 0.807 | 2.153 | 1.097 | 2.516 |
| 26 | Kyoto | E | 0.241 | 0.574 | 0.891 | 1.025 | 3.105 | 1.070 | 1.035 | 1.090 | 1.061 | 1.008 | 0.934 | 0.506 |
| 27 | Osaka | E | 1.516 | 1.148 | 0.833 | 0.600 | 1.006 | 0.911 | 0.922 | 0.974 | 1.063 | 1.064 | 0.979 | 0.810 |
| 28 | Hyogo | E | 1.005 | 0.787 | 0.324 | 0.371 | 1.835 | 0.972 | 1.945 | 0.799 | 0.904 | 1.044 | 0.870 | 0.248 |
| 29 | Nara | E | 1.300 | 1.513 | 0.952 | 0.947 | 0.979 | 1.015 | 0.980 | 1.050 | 1.076 | 1.225 | 1.091 | 2.389 |
| 30 | Wakayama | E | 1.108 | 1.083 | 0.396 | 1.031 | 0.840 | 0.536 | 0.851 | 0.784 | 0.742 | 0.874 | 0.791 | 0.095 |
| 31 | Tottori | F | 0.993 | 1.441 | 0.956 | 0.919 | 1.002 | 1.120 | 1.040 | 1.001 | 0.997 | 0.984 | 1.037 | 1.441 |
| 32 | Shimane | F | 1.008 | 0.971 | 0.981 | 0.996 | 1.239 | 0.972 | 0.997 | 1.007 | 0.937 | 1.006 | 1.009 | 1.090 |
| 33 | Okayama | F | 1.130 | 1.179 | 1.110 | 1.076 | 0.990 | 1.207 | 0.936 | 0.978 | 0.963 | 1.231 | 1.075 | 2.063 |
| 34 | Hiroshima | F | 1.047 | 0.638 | 0.980 | 5.647 | 0.771 | 1.081 | 0.987 | 0.990 | 0.659 | 1.021 | 1.073 | 2.024 |
| 35 | Yamaguchi | F | 1.400 | 0.679 | 1.243 | 1.389 | 1.765 | 1.419 | 1.172 | 1.111 | 1.353 | 0.836 | 1.197 | 6.050 |
| 36 | Tokushima | G | 1.021 | 1.006 | 1.001 | 0.947 | 1.084 | 0.968 | 1.029 | 1.057 | 0.989 | 1.037 | 1.013 | 1.140 |
| 37 | Kagawa | G | 1.003 | 0.982 | 0.999 | 0.996 | 1.027 | 0.943 | 0.994 | 1.018 | 0.968 | 0.999 | 0.993 | 0.930 |
| 38 | Ehime | G | 1.202 | 0.962 | 1.113 | 1.032 | 1.018 | 0.942 | 1.058 | 0.994 | 0.948 | 1.052 | 1.029 | 1.336 |
| 39 | Kochi | G | 1.081 | 0.968 | 1.012 | 1.030 | 1.126 | 1.039 | 1.019 | 1.072 | 0.940 | 0.961 | 1.023 | 1.260 |
| 40 | Fukuoka | H | 1.018 | 1.336 | 1.840 | 1.166 | 1.058 | 1.086 | 1.098 | 1.909 | 2.142 | 0.286 | 1.157 | 4.316 |
| 41 | Saga | H | 1.020 | 0.979 | 0.992 | 1.010 | 1.274 | 1.004 | 1.079 | 1.036 | 0.970 | 1.143 | 1.047 | 1.587 |
| 42 | Nagasaki | H | 1.098 | 1.105 | 0.980 | 0.985 | 1.108 | 0.959 | 0.990 | 0.980 | 0.999 | 1.032 | 1.022 | 1.244 |
| 43 | Kumamoto | H | 1.028 | 0.942 | 1.027 | 0.961 | 1.025 | 0.984 | 1.096 | 1.057 | 0.958 | 1.074 | 1.014 | 1.149 |
| 44 | Oita | H | 0.539 | 2.328 | 0.529 | 0.986 | 1.073 | 1.278 | 1.139 | 0.849 | 0.710 | 1.128 | 0.964 | 0.696 |
| 45 | Miyazaki | H | 1.504 | 2.169 | 1.227 | 0.794 | 1.224 | 1.010 | 1.647 | 0.724 | 0.868 | 1.966 | 1.231 | 8.007 |
| 46 | Kagoshima | H | 1.099 | 1.000 | 1.010 | 0.980 | 1.005 | 0.957 | 1.080 | 1.002 | 0.950 | 1.037 | 1.011 | 1.114 |
| 47 | Okinawa | H | 0.828 | 0.698 | 1.153 | 0.944 | 1.036 | 1.000 | 1.015 | 1.039 | 1.009 | 1.070 | 0.970 | 0.741 |
|  | Summary |  | 0.981 | 0.984 | 0.920 | 0.970 | 1.141 | 0.999 | 0.999 | 0.922 | 0.951 | 1.051 | 0.990 | 0.902 |

*Note*: A (Hokkaido), B (Tohoku), C (Kanto), D (Chubu), E (Kinki), F (Chugoku), G (Shikoku), and H (Kyushu).

**Table 7**
Summary of annual change of total-factor energy productivity index (TFEPI) and its components for each energy source.

| Energy source | Index | 93/94 | 94/95 | 95/96 | 96/97 | 97/98 | 98/99 | 99/00 | 00/01 | 01/02 | 02/03 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electric power for commercial and industrial use | TFEPI | 1.088 | 1.006 | 0.982 | 0.947 | 0.999 | 0.973 | 0.983 | 0.979 | 0.981 | 1.011 | 0.994 |
|  | TFEE change | 0.997 | 1.007 | 1.003 | 0.986 | 0.983 | 0.991 | 1.007 | 1.010 | 1.032 | 1.004 | 1.002 |
|  | Technical change | 1.092 | 0.999 | 0.978 | 0.961 | 1.016 | 0.982 | 0.976 | 0.969 | 0.951 | 1.007 | 0.992 |
| Kerosene | TFEPI | 1.042 | 0.957 | 1.025 | 1.013 | 1.041 | 0.965 | 1.026 | 1.011 | 0.953 | 1.062 | 1.009 |
|  | TFEE change | 0.987 | 1.008 | 1.011 | 1.024 | 0.998 | 0.973 | 1.024 | 1.031 | 1.015 | 1.005 | 1.007 |
|  | Technical change | 1.056 | 0.950 | 1.013 | 0.989 | 1.042 | 0.993 | 1.002 | 0.981 | 0.938 | 1.056 | 1.001 |
| Heavy oil | TFEPI | 1.002 | 0.986 | 0.993 | 1.011 | 1.065 | 0.976 | 0.999 | 0.991 | 0.992 | 0.999 | 1.001 |
|  | TFEE change | 1.003 | 0.993 | 1.005 | 0.983 | 1.011 | 0.989 | 1.006 | 0.988 | 1.033 | 0.976 | 0.999 |
|  | Technical change | 0.998 | 0.992 | 0.989 | 1.028 | 1.053 | 0.987 | 0.993 | 1.003 | 0.960 | 1.023 | 1.002 |
| Coal | TFEPI | 0.981 | 0.984 | 0.920 | 0.970 | 1.141 | 0.999 | 0.999 | 0.922 | 0.951 | 1.051 | 0.990 |
|  | TFEE change | 0.937 | 0.974 | 0.901 | 1.030 | 1.026 | 0.953 | 1.054 | 0.975 | 1.046 | 1.006 | 0.989 |
|  | Technical change | 1.047 | 1.009 | 1.021 | 0.941 | 1.112 | 1.048 | 0.948 | 0.946 | 0.910 | 1.044 | 1.001 |

**Table 8**
Number of times that each region was classified as an innovator by energy source.

| ID | Region | Area | Electric power for commercial and industrial use | Kerosene | Heavy oil | Coal | Total |
|---|---|---|---|---|---|---|---|
| 01 | Hokkaido | A | 2 | 0 | 1 | 1 | 4 |
| 02 | Aomori | B | 1 | 0 | 3 | 0 | 4 |
| 03 | Iwate | B | 2 | 3 | 6 | 0 | 11 |
| 04 | Miyagi | B | 0 | 0 | 0 | 0 | 0 |
| 05 | Akita | B | 3 | 1 | 5 | 3 | 12 |
| 06 | Yamagata | B | 4 | 3 | 5 | 4 | 16 |
| 07 | Fukushima | B | 5 | 7 | 3 | 3 | 18 |
| 08 | Ibaraki | C | 0 | 1 | 1 | 1 | 3 |
| 09 | Tochigi | C | 3 | 6 | 5 | 4 | 18 |
| 10 | Gunma | C | 0 | 4 | 2 | 1 | 7 |
| 11 | Saitama | C | 3 | 5 | 8 | 1 | 17 |
| 12 | Chiba | C | 0 | 0 | 0 | 0 | 0 |
| 13 | Tokyo | C | 5 | 5 | 5 | 5 | 20 |
| 14 | Kanagawa | C | 1 | 0 | 2 | 1 | 4 |
| 15 | Niigata | D | 0 | 0 | 0 | 0 | 0 |
| 16 | Toyama | D | 0 | 3 | 2 | 4 | 9 |
| 17 | Ishikawa | D | 5 | 4 | 3 | 5 | 17 |
| 18 | Fukui | D | 2 | 7 | 7 | 6 | 22 |
| 19 | Yamanashi | D | 1 | 6 | 6 | 6 | 19 |
| 20 | Nagano | D | 4 | 4 | 4 | 6 | 18 |
| 21 | Gifu | D | 0 | 3 | 3 | 0 | 6 |
| 22 | Shizuoka | D | 1 | 5 | 0 | 4 | 10 |
| 23 | Aichi | D | 0 | 1 | 0 | 0 | 1 |
| 24 | Mie | E | 0 | 0 | 0 | 1 | 1 |
| 25 | Shiga | E | 0 | 1 | 0 | 2 | 3 |
| 26 | Kyoto | E | 1 | 4 | 5 | 0 | 10 |
| 27 | Osaka | E | 0 | 2 | 4 | 2 | 8 |
| 28 | Hyogo | E | 0 | 0 | 0 | 0 | 0 |
| 29 | Nara | E | 6 | 7 | 9 | 6 | 28 |
| 30 | Wakayama | E | 0 | 0 | 0 | 0 | 0 |
| 31 | Tottori | F | 4 | 4 | 3 | 5 | 16 |
| 32 | Shimane | F | 2 | 7 | 5 | 4 | 18 |
| 33 | Okayama | F | 1 | 5 | 3 | 2 | 11 |
| 34 | Hiroshima | F | 0 | 0 | 0 | 0 | 0 |
| 35 | Yamaguchi | F | 0 | 0 | 0 | 0 | 0 |
| 36 | Tokushima | G | 0 | 7 | 4 | 7 | 18 |
| 37 | Kagawa | G | 1 | 4 | 4 | 3 | 12 |
| 38 | Ehime | G | 2 | 5 | 1 | 5 | 13 |
| 39 | Kochi | G | 4 | 6 | 7 | 0 | 17 |
| 40 | Fukuoka | H | 0 | 0 | 0 | 0 | 0 |
| 41 | Saga | H | 1 | 7 | 7 | 6 | 21 |
| 42 | Nagasaki | H | 4 | 4 | 0 | 4 | 12 |
| 43 | Kumamoto | H | 3 | 7 | 7 | 6 | 23 |
| 44 | Oita | H | 6 | 6 | 2 | 0 | 14 |
| 45 | Miyazaki | H | 3 | 8 | 6 | 5 | 22 |
| 46 | Kagoshima | H | 1 | 6 | 2 | 6 | 15 |
| 47 | Okinawa | H | 3 | 7 | 4 | 3 | 17 |
|  | Average |  | 1.787 | 3.511 | 3.064 | 2.596 | 10.957 |

*Note*: A (Hokkaido), B (Tohoku), C (Kanto), D (Chubu), E (Kinki), F (Chugoku), G (Shikoku), and H (Kyushu).

decision-making unit and look at such improvement cases in a positive light.

### 4.2. *Components of total-factor energy productivity growth*

Now we decompose the TFEPI into total-factor energy efficiency change and technical change. The former represents the change in relative efficiency of energy consumption among 47 regions; the latter represents the shift in the technology of energy use during one period.

Due to space limitations, we present only the summarized results for decomposition of the four energy sources in Table 7.[9] The TFEPI of electric power for commercial and industrial use changes by −0.6% annually. The TFEE change is 0.2%, while the technical change is −0.8%. The decomposition makes clear that the negative TFEPI change is caused by the technical change rather than the efficiency change. The electricity results suggest that the Japanese government should make more efforts in preventing productivity degradation of electricity use rather than enhancing energy productivity in relative inefficient regions. The TFEPI of kerosene changes by 0.9% annually, while the productivity progress during the period is largely attributable to the TFEE change of 0.7% rather than the technical change of 0.1%. The TFEPI change of heavy oil, 0.1%, can be decomposed into a TFEE change of −0.1% and a technical change of 0.2%. Finally, the TFEPI change of coal, −1.0%, can be largely attributed to a TFEE change of −1.1%, rather than a technical change of 0.1%. The coal results also imply a wide dispersion in coal efficiency changes.

All indices except coal's technical changes deteriorated in the period from 1998 to 1999. Meanwhile, all indices except heavy oil's TFEPI and TFEE improved in the period from 2002 to 2003. The TFEE changes of electricity and kerosene have been larger than unity since 1999, implying that the regions that have been inefficient caught up with the efficient regions with respect to the above two energy sources. Whereas every TFEE change improved

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[9] Full decomposition results are available on request from the authors.

during period 2001–2002, every energy source's technical change deteriorated.

Now we consider whether certain regions shifted the frontier over the course of the research period. Färe et al. (1994) use a component distance function in the technical change index to define 'innovators' who cause the frontier to shift. Accordingly, we can identify the innovators between period $t$ and $t$+1 if that region's:

Total-factor energy technical change $>1$,

$\mathrm{TFEE}_{t+1}^{t}>1$

and

$\mathrm{TFEE}_{t+1}^{t+1}=1$

Following the above definition, Table 8 shows the number of times each region became an innovator for each energy source. The regions most frequently observed as innovators for each energy source in the sample period are as follows: Nara and Oita (six times each) for electricity for commercial and industrial use; Miyazaki (eight times) for kerosene; Nara (nine times) for heavy oil; and Tokushima (seven times) for coal. The above four regions are located outside Japan's four major industrial areas.

The eight regions containing Japan's four major industrial areas, i.e., Chiba, Kanagawa, Gifu, Aichi, Mie, Osaka, Hyogo, and Fukuoka, tend not to be innovators frequently or at all for each energy source. Only two regions in the industrial areas, i.e., Saitama and Tokyo, were often innovators in the sample period. Tokyo was an innovator five times for each energy source. Geographically, the 11 regions belonging to the Shikoku and Kyushu areas, except Fukuoka, were frequently observed as innovators. These 11 regions are located in rural areas of Japan. To sum up these results, innovators were found only in a small proportion of the regions dominated by manufacturing industry. In other words, many of the regions that shift the frontier are not developing mainly on the basis of manufacturing industry.

## 5. Concluding remarks

In this study, we used a new approach that combines the concept of TFEE and the Malmquist productivity index to assess energy productivity growth in regions in Japan between 1993 and 2003. We computed TFEPI for four representative energy sources in a multiple-input framework to avoid single-input bias. This enabled us to compute single-factor productivity under a total-factor framework.

By separating out parts of TFEPI, we can identify both the catching up and innovation effects. The former effect indicates change in relative TFEE, and the latter effect indicates technical change. We can identify factors that reduce the energy efficiency of electric power for commercial and industrial use and coal. The TFEPI of electricity changed by −0.6% annually, which can be separated into a total-factor energy efficiency change of 0.2% and a technical change of −0.8%. The TFEPI for coal deteriorated 1.0%/year, which can be separated into a total-factor energy efficiency change of −1.1% and a technical change of 0.1%. From our findings, we conclude that deterioration in electricity efficiency is caused by a decrease in technical change, whereas that for coal is caused by a decrease in relative efficiency. The average annual net total-factor energy productivity changes of kerosene and heavy oil were 0.9% and 0.1%, respectively. Comparing TFEPI and consumption changes, we find that consumption of inefficient energy sources (electric power for commercial and industrial use and coal) has increased; and in contrast consumption of efficient sources (kerosene and heavy oil) has decreased. The best overall performers with respect to the TFEPIs for electric power for commercial and industrial use, kerosene, heavy oil, and coal were Hyogo, Okinawa, Nara, and Miyazaki, respectively; the worst performers were Shiga, Kanagawa, Ibaraki, and Kanagawa, respectively.

We defined and identified areas as 'innovators' that have caused the frontier to shift. Many innovators are found in regions outside Japan's four major industrial areas. Saitama and Tokyo are exceptions and are often observed as innovators. We conclude that the regions that shift the frontier in Japan are those that are not developing mainly on the basis of manufacturing industry. Regions in the industrial areas should improve their energy use technology and adjust their industrial structures.

In order to prevent depletion of natural resources and to meet the Kyoto target, Japan should improve its energy productivity. This new approach of total-factor energy productivity index serves to advance these purposes. The most important issue for future research is to examine what factors influence energy productivity. The relationships among energy price, per capita income, and energy productivity should be evaluated.

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