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RESEARCH ARTICLE

Economics of Waste Management and Disposal: Decoupling, Policy Enforcement and Spatial Factors

Waste generations and efficiency measures in Japan

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Abstract This study measures the efficiencies incorporating waste generation using Japanese prefecture level data. We apply and compare several models using directional distance functions. There are wide variations in the efficiency scores between the two orientations, "input, desirable and undesirable output orientation" and "undesirable output orientation". However, the difference in abatement factor does not result in wide variations in the efficiency scores. Our results show that there are wide differences in the efficiency scores among prefectures.

Keywords Efficiency · Waste generation · Data envelopment analysis · Undesirable output

JEL Classification Q53 · C61

1 Introduction

The increase in the generation of waste has caused serious concern in many countries including USA, Europe and Japan (see Powell et al. 2001; Shinkuma and Managi 2011, 2012). One of the main reasons for the concern is the shortage of final landfill areas. For example, the landfill areas for municipal waste and industrial

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waste are expected to be used up in the next 15.5 years (according to a 2008 estimate) and 7.7 years (according to a 2006 estimate) in Japan, respectively. Therefore, it is important to take waste emissions into account and analyze whether the region is generating less waste. We intend to analyze all regions in Japan. Although there are many previous studies on Japanese productivity using the prefecture level data (See Yamano and Ohkawara 2000; Managi 2003; Nemoto and Goto 2005; Nakano and Managi 2010) these studies do not include waste. Therefore in the context of studies on Japanese prefecture level productivity analysis, it is important to take waste generation into account.

We analyze the efficiency measure which is a part of productivity measures in Japan. Efficient production activities are considered to increase our welfare. However, when environmental externalities (i.e., undesirable output) are generated, welfare measures focusing on only marketable output (desirable output) and inputs (capital and labor) are not an adequate index to show our welfare. No matter how efficient the production of marketable goods, when the production process emits huge environmental burdens, the process is not successful in terms of social welfare. Therefore, we incorporate waste generation in efficiency measurement.

We use directional distance function by modified data envelopment analysis (DEA), which is a mathematical programing technique, to measure efficiency. Methodologies to incorporate undesirable output into efficiency measurement have been investigated in the literature. Färe et al. (1989) first applied the assumption of the weak disposability to undesirable output. Weak disposability implies that at the margin, firms can decrease undesirable outputs by decreasing the activity level. Currently, there are two major methodologies in the literature. One is advocated by Färe and Grosskopf 2003, 2009 and the other is advocated by Kuosmanen (2005) and Kuosmanen and Podinovski (2009). However, no empirical comparison has been reported other than Nakano and Managi (2010) in which the difference of the two technologies including CO_2 emissions is examined. Applying these recently discussed two methodologies, we compute efficiency with the weak disposability assumption on the undesirable output and incorporate waste generation as the undesirable outputs.

In measuring efficiency, we assume the variable returns to scale (VRS) production frontier. There is a debate over the form of the output set when using VRS frontier with undesirable outputs. The debate is regarding the assumption on the abatement factor. Färe and Grosskopf (2003, 2009) advocate the use of a uniform abatement factor across decision-making units. On the other hand, Kuosmanen (2005) and Kuosmanen and Podinovski (2009) suggest different abatement factors across decision-making units. Therefore, we measure the efficiencies with both assumptions on the abatement factor. If we find the values are similar, the results imply that the heterogeneity of the abatement factor is not important in Japanese regional level analysis for waste management. However, it is crucial to model the heterogeneity of the abatement factor in policy analysis.

After formulating the output set, we choose the measurements of the distance between each prefecture and the frontier (i.e., inefficiency). This study uses two orientations, "undesirable output orientation" and "input, desirable and undesirable output orientation.” In the undesirable output orientation model, we measure the distance based on the undesirable output reduction. On the other hand, in the “input, desirable and undesirable output orientation,” the distance is measured based on the proportional reduction in input and undesirable output and the proportional increase in desirable output. If two are found to be different, the choice of orientation has a profound effect on the efficiency.

Our results show that there are wide variations in the efficiency scores between the two orientations. However, the difference in abatement factor does not result in wide variations in the efficiency scores.

This paper is structured as follows. Section 2 describes the background. Section 3 describes the efficiency measures, while Sect. 4 presents the data. Section 5 describes the results. Finally, Sect. 6 provides concluding remarks.

2 Background

This paper uses DEA to measure efficiency [see Managi et al. (2004) for intuitive explanation of DEA]. The advantage of this approach is that the production technology is described without specifying functional forms. This mathematical programing technique was originally developed by Charnes et al. (1978) and Banker et al. (1984). In early studies, DEA deals only with desirable outputs. However, most production processes emit environmental burdens. As a result of increasing concern about environmental issues, some studies have examined the environmental externalities.

Shephard (1970) introduced the notion of the weak disposability of outputs. Applying this notion, Färe et al. (1989) propose several approaches for considering undesirable outputs. One of the approaches is to impose a weak disposability assumption on undesirable outputs and a strong disposability assumption on desirable outputs. This approach has been adopted in many studies (Yaisawarng and Klein 1994; Färe et al. 1996; Tyteca 1997; Taskin and Zaim 2001; Picazo-Tadeo et al. 2005; Kumar and Managi 2010; Fukuyama et al. 2011).

As for studies on Japan, some previous studies estimated the productivity of Japanese prefectures. Yamano and Ohkawara (2000), Managi (2003) and Nemoto and Goto (2005) estimated productivity using prefecture level data. However, they do not include the emissions of environmental burdens. Nakano and Managi (2010) consider CO_2 emissions but not include waste emissions.

We measure efficiency with the focus on Japanese prefectures using data from 2000 to 2003, including waste generation as the undesirable output. Our efficiency measures allow us to obtain more precise information on our welfare while not being biased toward the economic aspect.

3 Models of efficiency measurement

The production process assumes that the inputs are used to yield the desirable and undesirable outputs.

Let $\mathbf{x} = (x_1, \ldots, x_N) \in \mathbf{R}_+^N$ be the vectors of inputs. $\mathbf{y} = (y_1, \ldots, y_M) \in \mathbf{R}_+^M$ and $\mathbf{b} = (b_1, \ldots, b_J) \in \mathbf{R}_+^J$ are the vectors of desirable and undesirable outputs, respectively. Expression (1) defines the output sets that represent the technology:

$$P(\mathbf{x}) = \{(\mathbf{y}, \mathbf{b}) : \mathbf{x} \quad \text{can produce } (\mathbf{y}, \mathbf{b})\} \tag{1}$$

We assume that the output set is convex. We also assume the weak disposability of undesirable outputs which is expressed as:

$$\text{If} \quad (\mathbf{y}, \mathbf{b}) \in P(\mathbf{x}) \quad \text{and} \quad 0 \leq \theta \leq 1 \quad \text{then} \quad (\theta\mathbf{y}, \theta\mathbf{b}) \in P(\mathbf{x}). \tag{2}$$

When reducing undesirable outputs is achieved through decreasing the activity level, θ is interpreted as the abatement factor. On the other hand, as for inputs and desirable outputs, we assume strong disposability. The strong disposability of desirable outputs is expressed as:

$$\text{if } (\mathbf{y}, \mathbf{b}) \in P(\mathbf{x}) \quad \text{and} \quad \mathbf{y}' \leq \mathbf{y} \quad \text{then} \quad (\mathbf{y}', \mathbf{b}) \in P(\mathbf{x}) \tag{3}$$

The strong disposability of inputs is expressed as:

$$\text{if } (\mathbf{y}, \mathbf{b}) \in P(\mathbf{x}) \quad \text{and} \quad \mathbf{x} \leq \mathbf{x}' \quad \text{then} \quad (\mathbf{y}, \mathbf{b}) \in P(\mathbf{x}') \tag{4}$$

This means that desirable outputs and inputs can be discarded without using additional resources. We assume the VRS technology. Here we assume that at each time period, there are $k = 1,\ldots, K$ observations of inputs, desirable and undesirable outputs; $(\mathbf{x}_t^k, \mathbf{y}_t^k, \mathbf{b}_t^k)$. Therefore, using the Kuosmanen technology (Kuosmanen 2005; Kuosmanen and Podinovski 2009), we define the output set at time t as follows:

$$\hat{\mathbf{P}}_t^{\text{Kuosmanen}}(\mathbf{x}_t) = \left\{ (\mathbf{y}_t, \mathbf{b}_t) : \begin{array}{l} \sum_{k=1}^{K} \theta_t^k z_t^k y_{mt}^k \geq y_{mt}, \quad m = 1, \ldots, M \\ \sum_{k=1}^{K} \theta_t^k z_t^k b_{jt}^k = b_{jt}, \quad j = 1, \ldots, J \\ \sum_{k=1}^{K} z_t^k x_{nt}^k \leq x_{nt}, \quad n = 1, \ldots, N \\ \sum_{k=1}^{K} z_t^k = 1, \\ z_t^k \geq 0, \\ 0 \leq \theta_t^k \leq 1, \quad k = 1, \ldots, K \\ \text{for some } z_t^1, \ldots, z_t^K, \quad \theta_t^1, \ldots, \theta_t^K \end{array} \right\} \tag{5}$$

The directional distance function is defined as follows:

$$D_{T(t)}^W(\mathbf{x}_t, \mathbf{y}_t, \mathbf{b}_t; -\mathbf{g}_{xt}, \mathbf{g}_{yt}, -\mathbf{g}_{bt}) = \max\{\beta : (\mathbf{y}_t + \beta\mathbf{g}_{yt}, \mathbf{b}_t - \beta\mathbf{g}_{bt}) \in \hat{\mathbf{P}}_t^{\text{Kuosmanen}}(\mathbf{x}_t - \beta\mathbf{g}_{xt})\} \tag{6}$$

where $\mathbf{g} = \left(-\mathbf{g}_{xt}, \mathbf{g}_{yt}, -\mathbf{g}_{bt}\right)$ is a direction vector. β is the maximum proportional amount that desirable outputs can be expanded in the direction of $\mathbf{g}_{yt}$, while inputs and undesirable outputs can be reduced in the direction of $-\mathbf{g}_{xt}$ and $-\mathbf{g}_{bt}$, respectively, given the technology at time t, $T(t)$ which is defined by $\hat{\mathbf{P}}_t^{\text{Kuosmanen}}(\mathbf{x}_t)$. The superscript W means that the directional distance function is measured under the assumption of weak disposability of undesirable outputs.

In order to obtain the efficiency score β, we solve the mathematical programing problem. In "input, desirable and undesirable output orientation" measurement, the direction vector is set to $\mathbf{g} = \left(-\mathbf{g}_{xt}, \mathbf{g}_{yt}, -\mathbf{g}_{bt}\right) = (-\mathbf{x}_t, \mathbf{y}_t, -\mathbf{b}_t)$. Therefore, expression (7) gives us the efficiency score for production unit k' at time t:

$$\begin{aligned} & D_{T(t)}^{W(\text{Kuosmanen1})}\left(\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, \mathbf{b}_t^{k'}; -\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, -\mathbf{b}_t^{k'}\right) = \text{Max } \beta^{k'} \\ & s.t. \quad \sum_{k=1}^{K} \theta_t^k z_t^k y_{mt}^k \geq (1+\beta^{k'}) y_{mt}^{k'}, \quad m = 1, \ldots, M \\ & \sum_{k=1}^{K} \theta_t^k z_t^k b_{jt}^k = (1-\beta^{k'}) b_{jt}^{k'}, \quad j = 1, \ldots, J \\ & \sum_{k=1}^{K} z_t^k x_{nt}^k \leq (1-\beta^{k'}) x_{nt}^{k'}, \quad n = 1, \ldots, N \\ & \sum_{k=1}^{K} z_t^k = 1, \\ & z_t^k \geq 0,\ 0 \leq \theta_t^k \leq 1, \quad k = 1, \ldots, K \end{aligned} \tag{7}$$

On the other hand, in "undesirable output orientation" measurement, the direction vector is set to $\mathbf{g} = \left(-\mathbf{g}_{xt}, \mathbf{g}_{yt}, -\mathbf{g}_{bt}\right) = (\mathbf{0}_t, \mathbf{0}_t, -\mathbf{b}_t)$. Therefore, expression (8) gives us the efficiency score for production unit k' at time t:

$$\begin{aligned} & D_{T(t)}^{W(\text{Kuosmanen2})}\left(\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, \mathbf{b}_t^{k'}; \mathbf{0}, \mathbf{0}, -\mathbf{b}_t^{k'}\right) = \text{Max } \beta^{k'} \\ & s.t. \quad \sum_{k=1}^{K} \theta_t^k z_t^k y_{mt}^k \geq y_{mt}^{k'}, \quad m = 1, \ldots, M \\ & \sum_{k=1}^{K} \theta_t^k z_t^k b_{jt}^k = (1-\beta^{k'}) b_{jt}^{k'}, \quad j = 1, \ldots, J \\ & \sum_{k=1}^{K} z_t^k x_{nt}^k \leq x_{nt}^{k'}, \quad n = 1, \ldots, N \\ & \sum_{k=1}^{K} z_t^k = 1 \\ & z_t^k \geq 0,\ 0 \leq \theta_t^k \leq 1, \quad k = 1, \ldots, K \end{aligned} \tag{8}$$

While Kuosmanen (2005) and Kuosmanen and Podinovski (2009) suggest different abatement factors for different decision-making units, Färe and Grosskopf

(2003, 2009) advocate the same abatement factor among all the decision-making units. Based on Färe and Grosskopf technology [(Färe and Grosskopf (2003, 2009)], the output set is defined as follows:

$$\hat{\mathbf{P}}_t^{\text{Färe}}(\mathbf{x}_t) = \left\{ (\mathbf{y}_t, \mathbf{b}_t) : \theta_t \sum_{k=1}^{K} z_t^k y_{mt}^k \geq y_{mt}, \quad m = 1, \ldots, M \right.$$
$$\theta_t \sum_{k=1}^{K} z_t^k b_{jt}^k = b_{jt}, \quad j = 1, \ldots, J$$
$$\sum_{k=1}^{K} z_t^k x_{nt}^k \leq x_{nt}, \quad n = 1, \ldots, N$$
$$\sum_{k=1}^{K} z_t^k = 1$$
$$z_t^k \geq 0, \quad k = 1, \ldots, K$$
$$0 \leq \theta_t \leq 1,$$
$$\left. \text{for some} \quad z_t^1, \ldots, z_t^K \right\} \tag{9}$$

The directional distance function is defined as follows:

$$D_{T(t)}^W\left(\mathbf{x}_t, \mathbf{y}_t, \mathbf{b}_t; -\mathbf{g}_{xt}, \mathbf{g}_{yt}, -\mathbf{g}_{bt}\right) = \max\{\beta : (\mathbf{y}_t + \beta\mathbf{g}_{yt}, \mathbf{b}_t - \beta\mathbf{g}_{bt}) \in \hat{\mathbf{P}}_t^{\text{Färe}}(\mathbf{x}_t - \beta\mathbf{g}_{xt})\} \tag{10}$$

In order to obtain the efficiency score β, we solve the mathematical programing problem. In the "input, desirable and undesirable output orientation" measurement, solving (11) gives us the efficiency score for production unit k' at time t:

$$D_{T(t)}^{W\,(\text{Färe}1)}\left(\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, \mathbf{b}_t^{k'}; -\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, -\mathbf{b}_t^{k'}\right) = \text{Max } \beta^{k'}$$
$$s.t. \quad \theta_t \sum_{k=1}^{K} z_t^k y_{mt}^k \geq (1 + \beta^{k'}) y_{mt}^{k'}, \quad m = 1, \ldots, M$$
$$\theta_t \sum_{k=1}^{K} z_t^k b_{jt}^k = (1 - \beta^{k'}) b_{jt}^{k'}, \quad j = 1, \ldots, J$$
$$\sum_{k=1}^{K} z_t^k x_{nt}^k \leq (1 - \beta^{k'}) x_{nt}^{k'}, \quad n = 1, \ldots, N$$
$$\sum_{k=1}^{K} z_t^k = 1, \quad z_t^k \geq 0, \quad k = 1, \ldots, K$$
$$0 \leq \theta_t \leq 1 \tag{11}$$

Table 1 Model specifications

	Model A	Model B	Model C	Model D
Orientation	Input, desirable and undesirable output	Undesirable output	Input, desirable and undesirable output	Undesirable output
Technology as abatement factor	Different	Different	Same	Same
Expression	(7)	(8)	(11)	(12)

Kuosmanen technology assumes heterogeneous abatement factor while Färe and Grosskopf technology assumes uniform abatement factor

In the "undesirable output orientation" measurement, solving (12) gives us the efficiency score for production unit k' at time t:

$$
\begin{aligned}
& D_{T(t)}^{W\,(\text{Färe2})}\left(\mathbf{x}_t^{k'}, \mathbf{y}_t^{k'}, \mathbf{b}_t^{k'}; \mathbf{0}, \mathbf{0}, -\mathbf{b}_t^{k'}\right) = \text{Max}\ \beta^{k'} \\
& s.t. \quad \theta_t \sum_{k=1}^{K} z_t^k y_{mt}^k \geq y_{mt}^{k'}, \quad m = 1, \ldots, M \\
& \qquad \theta_t \sum_{k=1}^{K} z_t^k b_{jt}^k = (1 - \beta^{k'}) b_{jt}^{k'}, \quad j = 1, \ldots, J \\
& \qquad \sum_{k=1}^{K} z_t^k x_{nt}^k \leq x_{nt}^{k'}, \quad n = 1, \ldots, N \\
& \qquad \sum_{k=1}^{K} z_t^k = 1, \quad z_t^k \geq 0, \quad k = 1, \ldots, K \\
& \qquad 0 \leq \theta_t \leq 1
\end{aligned}
\tag{12}
$$

Table 1 summarizes the model specifications.

4 Data

This study uses data from 47 Japanese prefectures. The efficiencies are measured from the years 2000 to 2003. The analysis uses two inputs, one desirable output and one undesirable output.

The inputs are labor and private capital stock. In this study, we are not able to add material input because of the data unavailability. It is important to consider eco-efficiency defined by environmental load per material input (see Huppes and Ishikawa 2007). Our study, however, intends to apply production function approach. In production function, traditionally, capital and labor are the most essential inputs. The environmental load is a by-product of production. The importance of considering these inputs with desirable outputs production for analyzing environmental efficiency is discussed in Managi and Kaneko (2010). However, eco-efficiency is also important to examine efficiency and adding material is very important for future study.

We calculated the labor by multiplying the number of workers by average working hours for each prefecture. We obtained the data of the number of workers for each prefecture from the *Annual Report on Prefectural Accounts* published by the Cabinet Office, Government of Japan. The data of the working hours for each prefecture are obtained from the *Monthly Labor Statistical Survey* published by the Ministry of Health, Labor and Welfare. We obtained the data of private capital stock from the *CRIEPI Regional Economic Database* estimated by the Socio-economic Research Center, Central Research Institute of Electric Power Industry, Tokyo.

The desirable output is the annual real production by each prefecture, which is estimated in Kainou (2006, 2007). These studies calculate the annual real production based on the *Annual Report on Prefectural Accounts* published by the Cabinet Office, Government of Japan (the base year of the statistics is 1995).

The undesirable output is waste generation. In the basic act in establishing a sound material-cycle society (promulgated in 2000), the priority of material cycle measures is explained. In the law, reducing waste generation is given the top priority followed by reuse, reclamation, heat recovery and proper disposal. The lower priority measures require energy or lands that are scarce in Japan. Therefore, this study focuses on waste generation. In this study, the waste consists of industrial waste and general waste from business activities. We obtained prefectural waste generation data from *the Industrial Waste Generation and Disposal* and *the Survey on the General Waste Disposal* published by the Ministry of the Environment. As for the industrial waste, the prefectural surveys on industrial waste generation are not carried out every year. The timing of the implementation of the survey is different among prefectures. Therefore, the data include estimates from output or labor. From the nature of the data, we have to keep in mind that the comparison of efficiencies among prefectures or periods includes the limitations.

5 Results

The average efficiency scores for each sample period are shown in Table 2.[1] In DEA analysis, the efficiency score means the difference from the frontier activities. Therefore, a zero efficiency score means that a prefecture is on the frontier and a large score implies that there are large differences between the performance of the

[1] There are two factors that have the impact on the relationship between the efficiency scores based on Kuosmanen technology and those based on Färe and Grosskopf technology. (1) The efficiency scores of model A may be equal to or larger than those of model C because the frontier of Kuosmanen technology is larger than that of Färe and Grosskopf technology. (2) In Kuosmanen technology, in calculating efficiency scores of a specific prefecture k', DEA decides z^k and θ^k in order to make prefecture k' more efficient compared to the case where z^k and θ^k take the other values. On the other hand, in Färe and Grosskopf technology, θ is common to all the prefectures. Therefore, Färe and Grosskopf technology is more restrictive than Kuosmanen technology. Due to the restriction, the efficiency scores of prefecture k' calculated under Färe and Grosskopf technology may not take smaller value than those calculated under Kuosmanen technology. Therefore, efficiency scores may be smaller in model A than those in model C. Since there are two effects, the relationship of the scores of models A and C cannot be decided in advance. In this study, Aichi, Ishikawa, Kyoto, Osaka, Hyogo and Hiroshima prefecture have smaller efficiency scores when they calculated under Kuosmanen technology than under Färe and Grosskopf technology.

Table 2 The average efficiency scores for each year

	Model A	Model B	Model C	Model D
2000	0.04598	0.50333	0.04601	0.49212
2001	0.04702	0.49681	0.04702	0.47729
2002	0.04533	0.48841	0.04532	0.47062
2003	0.03833	0.50974	0.03834	0.49764

Table 3 The possible reduction in waste generation (1,000 tons)

	Model A	Model B	Model C	Model D
2000	15,897	202,479	15,921	199,220
2001	16,579	200,625	16,579	194,330
2002	15,843	190,281	15,851	184,985
2003	14,170	211,787	14,184	207,514

prefecture on the frontier and that of the other prefectures. When we focus on only waste (Models B and D), the scores are larger than those of Models A and C. Large scores mean that some prefectures have large distance to the frontier.

In Japan, in the law of the basic act for establishing a sound material-cycle society, the reduction of waste generation is most important followed by reuse and recycle activities. In this study, waste generation is used as the undesirable output. Therefore, we examine the effect of the reduction in waste generation. However, these scores are large. This means that the production activities in Japan have a large variance and there is a huge difference in the performance between the advanced prefectures and others. On the other hand, for input, desirable and undesirable output orientation model (Models A and C), the scores are much smaller than those of Models B and D. Models A and C examine the room for proportional increase in desirable output and proportional decrease in inputs and undesirable output. Therefore, the constraints of the measurement are stricter than those in Models B and D. This is considered to result in the smaller scores in Models A and C.

From the above investigation, we found that there are some inefficient prefectures in all models. How much waste generation should be reduced for prefectures located not on the frontier to achieve the frontier? We calculated the necessary reduction in waste generation. The results are summarized in Table 3. We need to keep in mind that the results are not necessary related to the feasibility. According to Table 3, the figures in Models A and C are smaller than those in Models B and D. Therefore, when the management of inputs and desirable output does not have much room to improve, waste generation cannot be reduced much. Therefore, the small figures in Models A and C show the relatively efficient activities in inputs and desirable output. On the other hand, Models B and D show relatively large figures because they focus on only waste management activities. This means that there is a wide variance in waste management activities among the prefectures.

For the investigation of the differences in areas, Figs. 1, 2, 3 and 4 show the average efficiency scores of each prefecture during the sample period under Models A, B, C, and D, respectively. As for the Kuosmanen technology, Hokkaido, Saitama, Tokyo, Shiga, Nara and Tottori prefectures are efficient in both orientations. However, Chiba, Yamaguchi, Ehime and Miyazaki prefectures are efficient in "input, desirable and undesirable output orientation", while inefficient in "undesirable output orientation". This is same for the Färe and Grosskopf technologies.

According to *the Annual Report on Prefectural Accounts* in 2003, as for the industrial sector's production amount, Tokyo ranked first and Tottori ranked last (the share of each prefecture relative to the whole of Japan is 18.37 and 0.38 %,

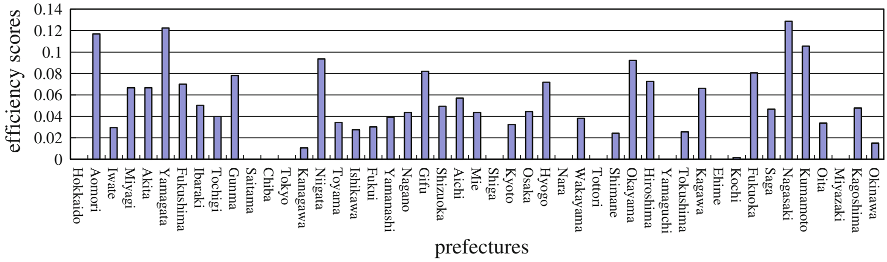

Fig. 1 Model A efficiency scores

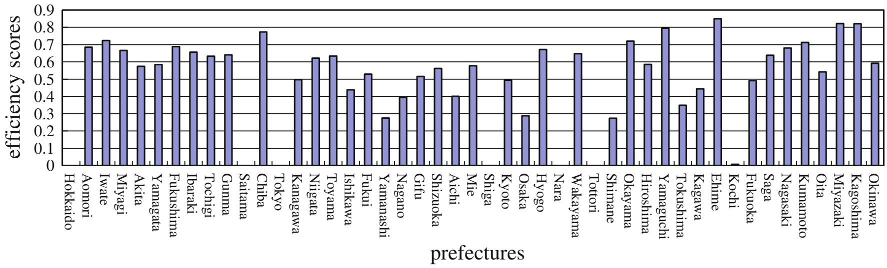

Fig. 2 Model B efficiency scores

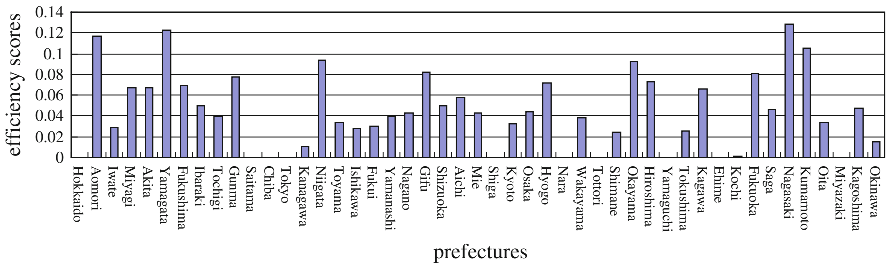

Fig. 3 Model C efficiency scores

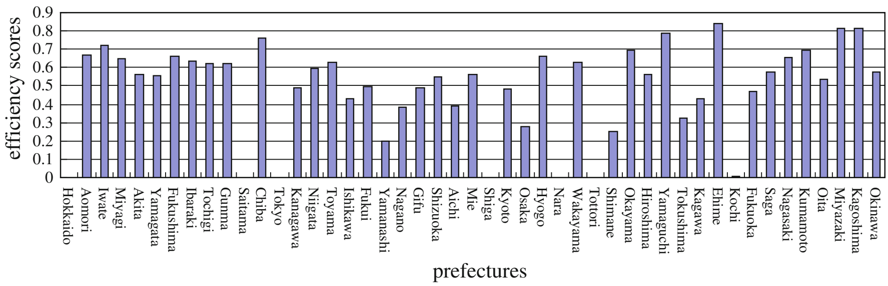

Fig. 4 Model D efficiency scores

respectively). Since both of them are on the frontier, the size of the economic activities is not related to the efficiency. This is the advantage of using variable returns to scale technologies.

Some prefectures are interpreted as efficient using “input, desirable and undesirable output orientation”, while inefficient in “undesirable output orientation”. In the latter model, for example, the reference prefecture for Chiba in 2000 is Tokyo. The amount of waste generation in Chiba is almost the same as that in Tokyo. However, the annual real production amount in Chiba is about 0.2 times of that in Tokyo. In addition, labor and capital are almost about 0.25 times of those in Tokyo. Therefore, Chiba is considered to generate large amount of waste compared to the size of marketable activities. Therefore, Chiba is calculated to be inefficient compared to Tokyo. However, does this mean Chiba lags behind Tokyo? The industrial structure of Chiba and Tokyo is different. The size of the tertiary industry in Tokyo is about five times larger than that in Chiba. The size of the secondary industry in Tokyo is about three times larger than that in Chiba. However, the size of the primary industry in Tokyo is only about 0.2 times compared to the size in Chiba. Therefore, when a prefecture is depending on less waste generation industry to obtain marketable good, the efficiency score of the prefecture will become small. In “input, desirable and undesirable output orientation” model, Chiba is on the frontier. This shows that marketable activities in Chiba does not have much room to improve.

In order to examine whether there are differences in the results between the “Kuosmanen technology” and “Färe and Grosskopf technology”, we conducted the Wilcoxen signed rank test. We calculate the average efficiency scores of each prefecture and conducted the test. The null hypothesis is that there is no difference between “Kuosmanen technology” and “Färe and Grosskopf technology” in population. In the comparison between Models A and C, the test statistic is 13. In the comparison between Models B and D, the test statistic is 861. The results are not significant at the 5 % level.

6 Conclusion

This study measured Japanese prefectures’ efficiencies from 2000 to 2003 taking waste generations into consideration. We used several measures and compared the results. There are wide variations in the efficiency scores between the two orientations, “input, desirable and undesirable output orientation” and “undesirable output orientation”. However, the difference in abatement factor does not result in wide variations in the efficiency scores. Our results show that there are wide differences in the efficiency scores among prefectures.

In this study, we apply production function approach where labor and private capital stock are inputs and desirable and undesirable outputs are produced. For the future work of efficiency in terms of environmental issues, material input plays an important role. Therefore, it is crucial to analyze the eco-efficiency defined by environmental load per material input. Using both our efficiency scores and eco-efficiency scores, we will be able to better judge totally the production process.

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