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A preference allocation-DFM model in Data Envelopment Analysis -An application to Energy-Environment-Economic efficiency in Japan-

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A preference allocation-DFM model in Data Envelopment Analysis -An application to Energy-Environment-Economic efficiency in Japan-

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Abstract

Japan is faced with a ‘Fukushima’ problem, meaning a nuclear accident leading to electrical power shortage. This problem relates to a non-balanced ‘Energy-Environment-Economic’ policy which does not, but should incorporate ‘electrical power saving’, ‘low carbon emission’, and ‘economic growth’. Although it is difficult at this stage, it is necessary to make an effort to achieve more balanced and more efficient ‘Energy-Environment-Economic’ policy in Japan, even if Japan decides to withdraw from the COP (Conference of Parties of United Nations Conventions) 17.

A standard tool to judge the efficiency of actors (decision making units) is Data Envelopment Analysis (DEA). The existence of many possible efficiency improvement solutions has in recent years prompted a -rich variety of literature on the methodological integration of the MOLP (Multiple Objective Linear Programming) and the DEA models. In the past years, much progress has been made to extend this approach in several directions. An example is the Distance Friction Minimization (DFM) method.

The DFM model is based on a generalized distance friction function and serves to improve the performance of a Decision Making Unit (DMU) by identifying the most appropriate movement towards the efficiency frontier surface. Standard DEA models use a uniform proportional input reduction (or a uniform proportional output increase) in the improvement projections, but the DFM approach aims to enhance efficiency strategies by introducing a weighted projection function. This approach may address both input reduction and output increase as a strategy of a DMU. An advantage of this model is that there is no need to incorporate the value judgment of a decision maker. Nevertheless, in order to achieve efficiency improvement in Japan’s ‘Energy-Environment-Economic’ policy at a regional level, it might be necessary to incorporate a value judgment of a policy maker on political priorities.

In our study, we present a newly developed Preference Allocation model in DFM, which is suitable to incorporate a decision maker’s value judgment for the allocation of an input reduction and an output augmentation in an efficiency improvement projection. The above-mentioned Preference Allocation model is illustrated on the basis of an application to the efficiency analysis of ‘Energy-Environment-Economic’ for each prefecture in Japan.

Keywords: Data Envelopment Analysis (DEA), Distance Friction Minimization (DFM), Preference Allocation (PA),

Energy-Environment-Economic efficiency

JEL code: C00, R58, Q48

1. Introduction

Japan is faced with a ‘Fukushima’ problem, meaning a nuclear accident leading to electrical power shortage. This problem relates to a non-balanced ‘Energy-Environment-Economic’ policy which does not, but should incorporate ‘electrical power saving’, ‘low carbon emission’, and ‘economic growth’. Although it is difficult at this stage, it is necessary to make an effort to achieve more balanced and more efficient ‘Energy-Environment-Economic’ policy in Japan, even if Japan decides to withdraw from the COP (Conference of Parties of United Nations Conventions) 17.

A standard tool to judge the efficiency is Data Envelopment Analysis (DEA). Seiford (2005) mentions some 2800 published articles on DEA. This large number of studies shows that comparative efficiency analysis has become an important topic.

DEA was developed to analyze the relative efficiency of a Decision Making Unit (DMU), by constructing a piecewise linear production frontier, and projecting the performance of each DMU onto the frontier. A DMU that is located on the frontier is efficient, while a DMU that is not on the frontier is inefficient. An inefficient DMU can become efficient by reducing its inputs or increasing its outputs. In the standard DEA approach, this is achieved by a uniform reduction in all inputs (or a uniform increase in all outputs). But, in principle, there are an infinite number of improvements to reach the efficient frontier, and hence there are many solutions if a DMU plans to enhance its efficiency.

The existence of many possible efficiency improvement solutions has in recent years prompted a rich literature on the methodological integration of the MOLP (Multiple Objective Linear Programming) and the DEA models. As mentioned, the first contribution was made by Golany (1988) who proposed an interactive MOLP procedure which aimed at generating a set of efficient points for a DMU. This model allows a decision maker to select the preferred set of output levels, given the input levels. Next, Thanassoulis and Dyson (1992) developed adjusted models which can be used to estimate alternative input and output levels in order to render relatively inefficient DMUs more efficient. These models are able to incorporate preferences for a potential improvement of individual input and output levels. The resulting target levels reflect the user’s relative preference over alternative paths to efficiency. Joro et al. (1998) demonstrated the analytical similarity between a DEA model and a Reference Point Model in a MOLP formulation from a mathematical viewpoint. In addition, the Reference Point Model provides suggestions which make it possible to search freely on the efficient frontier for good solutions or for the most preferred solution based on the decision maker’s preference structure. More recently, Halme et al. (1999) developed a Value Efficiency Analysis (VEA), which included the decision maker’s preference information in a DEA model. The foundation of VEA

originates from the Reference Point Model in a MOLP context. Here the decision maker identifies the Most Preferred Solution (MPS), so that each DMU can be evaluated by means of the assumed value function based on the MPS approach. A further development of this approach was made by Korhonen and Siljamäki (2002) who dealt with several practical aspects related to the use of a VEA. In addition, Korhonen et al. (2003) developed a multiple objective approach which allows for changes in the time frame. And, finally, Lins et al. (2004) proposed two multi-objective approaches that determine the basis for the incorporation of a posteriori preference information. The first of these models is called MORO (Multiple Objective Ratio Optimization), which optimizes the ratios between the observed and the target inputs (or outputs) of a DMU. The second model is MOTO (Multiple Objective Target Optimization), which directly optimizes the target values.

Suzuki et al. (2010) proposed a Distance Friction Minimization (DFM) model that is based on a generalized distance friction function, and serves to improve the performance of a DMU by identifying the most appropriate movement towards the efficiency frontier surface. This approach may address both an input reduction and an output increase as a strategy of a DMU. An advantage of this model is not need to incorporate the value judgment of a decision maker. Nevertheless, in order to achieve efficiency improvement in Japan's "Energy-Environment-Economic" policy at a regional level, it might be necessary to incorporate a value judgment of a policy maker on political priorities.

In our study, we present a newly developed Preference Allocation model in DFM, which is suitable to incorporate a decision maker's value judgment for the allocation of an input reduction and an output augmentation in an efficiency improvement projection.

The above-mentioned Preference Allocation model is illustrated on the basis of an application to the efficiency analysis of "Energy-Environment-Economic" for each prefecture in Japan.

2. Efficiency Improvement Projection in DEA

2.1 CCR model

The standard Charnes et al. (1978) model (abbreviated hereafter as the CCR-input model) for a given DMU_{*j*} (*j* = 1, ..., *J*) to be evaluated in any trial *o* (where *o* ranges over 1, 2 ..., *J*) may be represented as the following fractional programming (*FP_o*) problem:

$$(FP_o) \quad \max_{v,u} \quad \theta = \frac{\sum_s u_s y_{so}}{\sum_m v_m x_{mo}}$$

$$\text{s.t.} \quad \frac{\sum_s u_s y_{sj}}{\sum_m v_m x_{mj}} \leq 1 \quad (j=1, \dots, J) \quad (2.1)$$

$$v_m \geq 0, \quad u_s \geq 0,$$

where θ represents an objective variable function (efficiency score); x_{mj} is the volume of input m ($m=1, \dots, M$) for DMU $_j$ ($j=1, \dots, J$); y_{sj} is the output s ($s=1, \dots, S$) of DMU $_j$; and v_m and u_s are the weights given to input m and output s , respectively. Model (2.1) is often called an input-oriented CCR model, while its reciprocal (i.e. an interchange of the numerator and denominator in the objective function (2.1), with a specification as a minimization problem under an appropriate adjustment of the constraints) is usually known as an output-oriented CCR model. Model (2.1) is obviously a fractional programming model, which may be solved stepwise by first assigning an arbitrary value to the denominator in (2.1), and then maximizing the numerator.

The improvement projection (\hat{x}_o, \hat{y}_o) can now be defined in (2.2) and (2.3) as:

$$\hat{x}_o = \theta^* x_o - s^{-*}; \quad (2.2)$$

$$\hat{y}_o = y_o + s^{+*}. \quad (2.3)$$

These equations indicate that the efficiency of (x_o, y_o) for DMU $_o$ can be improved if the input values are reduced radially by the ratio θ^* , and the input excesses s^{-*} are eliminated (see Figure 1). The original DEA models presented in the literature have thus far only focused on a uniform input reduction or a uniform output increase in the efficiency-improvement projections, as shown in Figure 1 ($\theta^* = OC'/OC$).

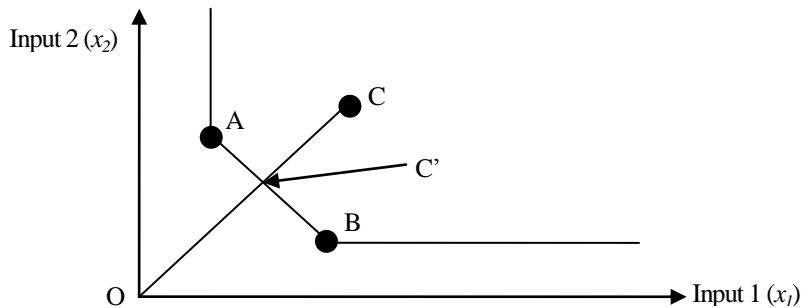


Figure 1 Illustration of original DEA projection in input space

2.2 Super-Efficiency model

The unsatisfactory identification of efficient DMUs in a standard DEA model – where all efficient DMUs get the score 1 – has led to focused research to discriminate between efficient DMUs, in order to arrive at a ranking – or even numerical rating – of these efficient DMUs, without affecting the results for the non-efficiency. In particular, Andersen and Petersen (1993) developed a radial Super-Efficiency model, while later on Tone (2002, 2003) designed a *slacks-based* measure (SBM) of super-efficiency in DEA. In general, a Super-Efficiency model aims to identify the relative importance of each individual efficient DMUs, by designing and measuring a score for its ‘degree of influence’ if this efficient DMU is omitted from the efficiency frontier (or production possibility set). If this elimination really matters (i.e. if the distance from this DMU to the remaining efficiency frontier is large), and thus the firm concerned has a high degree of influence, and outperforms the other DMUs, it gets a high score (and is thus super-efficient). Thus, for each individual DMU a new distance result is obtained, which leads to a new ranking – even a rating – of all original efficient DMUs.

Anderson and Petersen (1993) have developed the Super-Efficiency model based on Radial projection (including CCR model) to arrive at a ranking of all efficient DMUs. The efficiency scores from a super-efficiency model are thus obtained by eliminating the data on the DMU_o to be evaluated from the solution set. For the input model, this can then result in values which may be regarded – according to the DMU_o – as a state of super-efficiency. These values are then used to rank the DMUs and, consequently, efficient DMUs may then obtain an efficiency score above 1.000. The super-efficiency model may be suitable to find for highest performing prefecture.

The super-efficiency model based on a CCR-I model can now be written as follows:

$$\begin{aligned}
 & \min_{\theta, \lambda, s^-, s^+} \quad \theta - es^- - es^+ \\
 \text{s.t.} \quad & \theta x_o = \sum_{j=1, \neq o}^J \lambda_j x_j + s^- \\
 & y_o = \sum_{j=1, \neq o}^J \lambda_j y_j - s^+ \\
 & \lambda_j, s^-, s^+ \geq 0
 \end{aligned} \tag{2.4}$$

where e is a unit vector (1, ..., 1), representing a utility factor for all elements. This model will be used in our search for ‘Exceptional Places’.

3. The Distance Friction Minimization (DFM) Approach

3.1 Illustration of the DFM model

As mentioned, the efficiency improvement solution in the original CCR-input model requires that the input values are reduced radially by a uniform ratio θ^* ($\theta^* = OD'/OD$ in Figure 2).

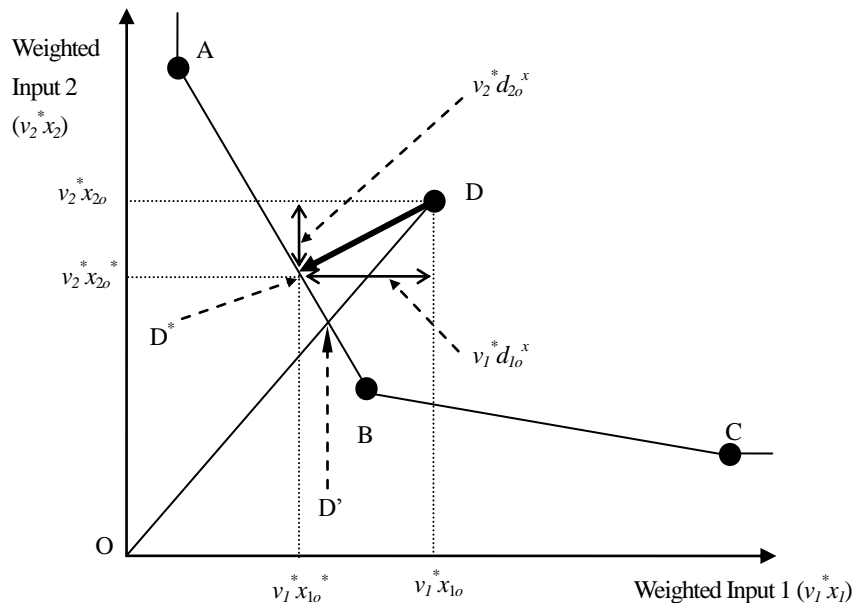


Figure 2 Illustration of the DFM approach (Input- $v_i x_i$ space)

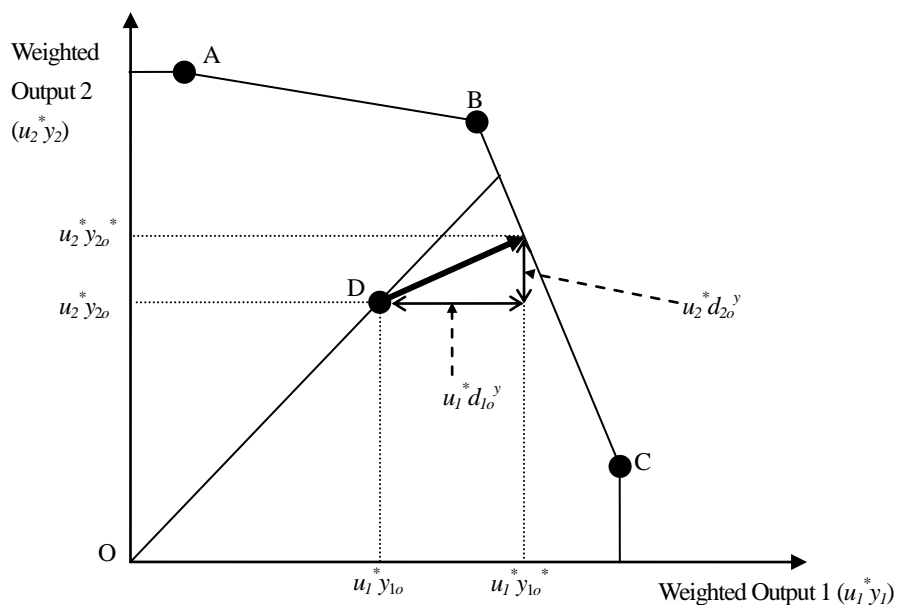


Figure 3 Illustration of the DFM approach (Output - $u_r y_r$ space)

The (v^*, u^*) values obtained as an optimal solution for formula (2.1) result in a set of optimal weights for DMU_o. As mentioned earlier, (v^*, u^*) is the set of most favourable weights for DMU_o, in the sense of maximizing the ratio scale. v_m^* is the optimal weight for the input item m , and its magnitude expresses how much in relative terms the item is contributing to efficiency. Similarly, u_s^* does the same for the output item s . These values show not only which items contribute to the performance of DMU_o but also to what extent they do so. In other words, it is possible to express the distance frictions (or alternatively, the potential increases) in improvement projections.

In this study, we use the optimal weights u_s^* and v_m^* from (2.1), and then describe the efficiency improvement projection model. A visual presentation of this new approach is given in Figures 2 and 3. In this approach a generalized distance friction is employed to assist a DMU to improve its efficiency by a movement towards the efficiency frontier surface. The direction of efficiency improvement depends, of course, on the input/output data characteristics of the DMU. It is now appropriate to define the projection functions for the minimization of distance friction by using a Euclidean distance in weighted spaces. As mentioned, a suitable form of multidimensional projection functions that serves to improve efficiency is given by a MOQP model which aims to minimize the aggregated input reduction frictions, as well as the aggregated output increase frictions. Thus, the DFM approach can generate a new contribution to efficiency enhancement problems in decision analysis by employing a weighted Euclidean projection function, and, at the same time, it may address both input reduction and output increase. Here, we will only briefly describe the various steps.

First, the distance friction function Fr^x and Fr^y is specified by means of (3.1) and (3.2), which are defined by the Euclidean distance shown in Figures 2 and 3. Next, the following MOQP is solved by using d_{mo}^x (a reduction of distance for x_{io}) and d_{so}^y (an increase of distance for y_{so}) as variables:

$$\min Fr^x = \sqrt{\sum_m (v_m^* x_{mo} - v_m^* d_{mo}^x)^2} \quad (3.1)$$

$$\min Fr^y = \sqrt{\sum_s (u_s^* y_{so} - u_s^* d_{so}^y)^2} \quad (3.2)$$

$$\text{s.t.} \quad \sum_m v_m^* (x_{mo} - d_{mo}^x) = \frac{2\theta^*}{1 + \theta^*} \quad (3.3)$$

$$\sum_s u_s^* (y_{so} + d_{so}^y) = \frac{2\theta^*}{1 + \theta^*} \quad (3.4)$$

$$x_{mo} - d_{mo}^x \geq 0 \quad (3.5)$$

$$d_{mo}^x \geq 0 \quad (3.6)$$

$$d_{so}^y \geq 0, \quad (3.7)$$

where x_{mo} is the amount of input item m for any arbitrary inefficient DMU_o, and y_{so} is the amount of output item s for any arbitrary inefficient DMU_o. The constraint functions (3.3) and (3.4) refer to the target values of input reduction and output augmentation. The fairness in the distribution of contributions from the input and output side to achieve efficiency is established as follows. The total efficiency gap to be covered by inputs and outputs is $(1-\theta^*)$. The input and the output side contribute according to their initial levels 1 and θ^* , implying shares $\theta^*/(1+\theta^*)$ and $1/(1+\theta^*)$ in the improvement contribution. Clearly, the contributions from both sides equal $(1-\theta^*)[\theta^*/(1+\theta^*)]$, and $(1-\theta^*)[1/(1+\theta^*)]$. Hence, we find for the input reduction target and the output augmentation targets:

$$\text{Input reduction target: } \sum_m v_m^* (x_{mo} - d_{mo}^x) = 1 - (1 - \theta^*) \times \frac{1}{(1 + \theta^*)} = \frac{2\theta^*}{1 + \theta^*}. \quad (3.8)$$

$$\text{Output augmentation target: } \sum_s u_s^* (y_{so} + d_{so}^y) = \theta^* + (1 - \theta^*) \times \frac{\theta^*}{(1 + \theta^*)} = \frac{2\theta^*}{1 + \theta^*}. \quad (3.9)$$

An illustration of the above situation is given in Figure 4.

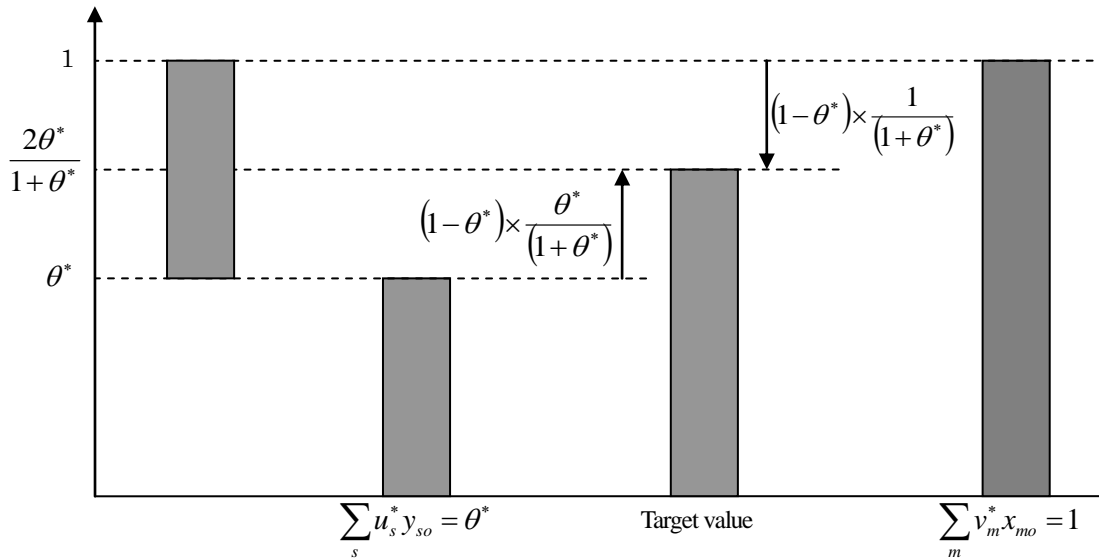


Figure 4 Presentation of a balanced allocation for the total efficiency gap

It is now possible to determine each optimal distance d_{mo}^{x*} and d_{so}^{y*} by using the MOQP model (3.1)-(3.7). The friction minimization solution for an inefficient DMU_o can be expressed by means of formulas (3.9) and (3.10):

$$x_{mo}^* = x_{mo} - d_{mo}^{x*}; \quad (3.9)$$

$$y_{so}^* = y_{so} + d_{so}^{y*}. \quad (3.10)$$

By means of the DFM model, it is possible to present a new efficiency-improvement solution based on the standard CCR projection. This means an increase in new options for efficiency-improvement solutions in DEA. The main advantage of the DFM model is that it yields an outcome on the efficient frontier that is as close as possible to the DMU's input and output profile (see Figure 5).

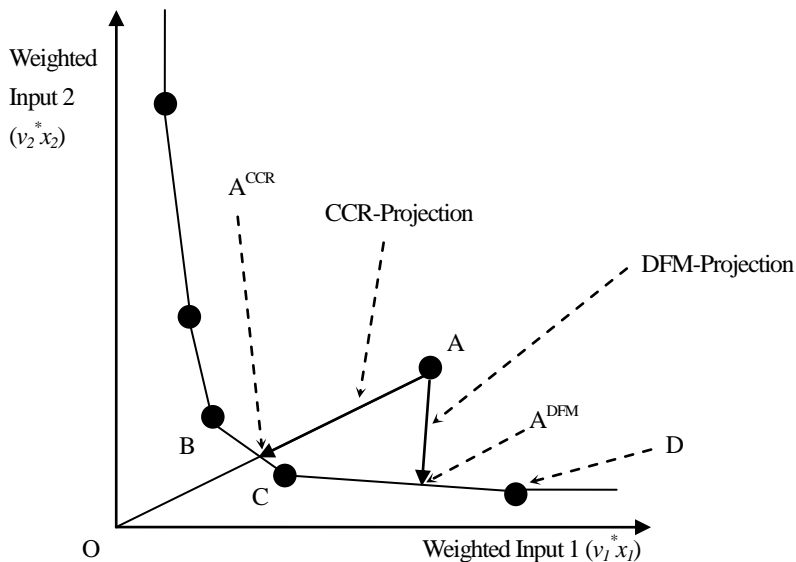


Figure 5 Degree of improvement of DFM and CCR projection in weighted input space

3.2 A Super-Efficiency DFM model

We used a Super-Efficiency DFM model based on CCR-I that is integrated with a Super-Efficiency DEA model.

In a normal DFM model, the (v^*, u^*) values obtained as an optimal solution for formula (2.1) result in a set of optimal weights for DMU_o. Super-Efficiency DFM model (hereafter SE-DFM) is now based on the idea that these optimal values result from the application of the Super-Efficiency model. The advantage of the SE-DFM model is that it yields an unambiguous and measurable outcome in a ranking of efficient DMUs, i.e. this integrated model can be suitable to find the highest performing DMUs, while retaining all the advantages of the DFM model.

4. Preference Allocation model in DFM

In this study we newly proposed a Preference Allocation (PA) model in the framework of the DFM model. The PA model specifies a Output Allocation Parameter (OAP) of the total efficiency gap $(1-\theta^*)$ in the DFM model. The value of the OAP ranges from 0 to 1. For example, if OAP is specified to be 1.0, then the PA model can compute an efficiency improving projection that the total efficiency gap $(1-\theta^*)$ is full allocated for output augmentation. If OAP is specified to be 0.7, then the PA model can compute an efficiency improving projection that 70% of total efficiency gap $(1-\theta^*)$ is allocated for output augmentation, and 30% of total efficiency gap $(1-\theta^*)$ is allocated for input reduction. And, if OAP is specified to be 0.0, then the PA model can compute an efficiency improving projection that the total efficiency gap $(1-\theta^*)$ is full allocated for input reduction.

This model will use the constraint functions (4.1) and (4.2) instead of constraint functions (3.3) and (3.4) in the DFM model.

$$\text{s.t.} \quad \sum_m v_m^* (x_{mo} - d_{mo}^x) = \theta^* + OAP(1 - \theta^*) \quad (4.1)$$

$$\sum_s u_s^* (y_{so} + d_{so}^y) = \theta^* + OAP(1 - \theta^*) \quad (4.2)$$

A visual presentation of constraint functions (4.1) and (4.2) is given in Figure 6.

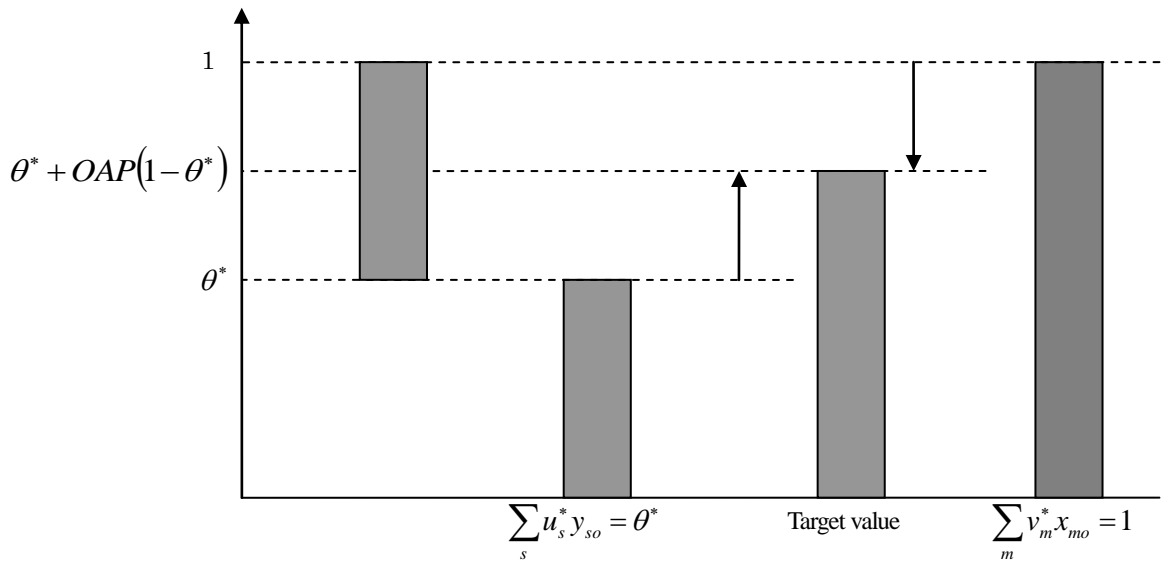


Figure 6 Presentation of a preference allocation for the total efficiency gap

First, the PA model has arbitrarily specified a OAP (it is just a decision maker’s value judgment for allocation percentage of an output augmentation) of the total efficiency gap $(1-\theta^*)$. Next, the target value, which are allocated between input efforts and output efforts based on OAP, are computed in Figure 6 using constraint functions (4.1) and (4.2). Finally, we can compute an input reduction value and an output increase value based on DFM model.

This original model is named “Preference Allocation DFM (PA-DFM hereafter)” model.

5. An application of Super-Efficiency and PA-DFM Model for Energy-Environment-Economic efficiency in Japan.

5.1 Database and analysis framework

In our empirical work, we use the following inputs and outputs data for a set of 46 prefectures in Japan, and as figure 7. We eliminated Tokyo in DMUs in order to compute a realistic improving projection for each prefecture, because a lot of companies are based at Tokyo, then CDP of Tokyo is excessively accounted than an actual economic performance.

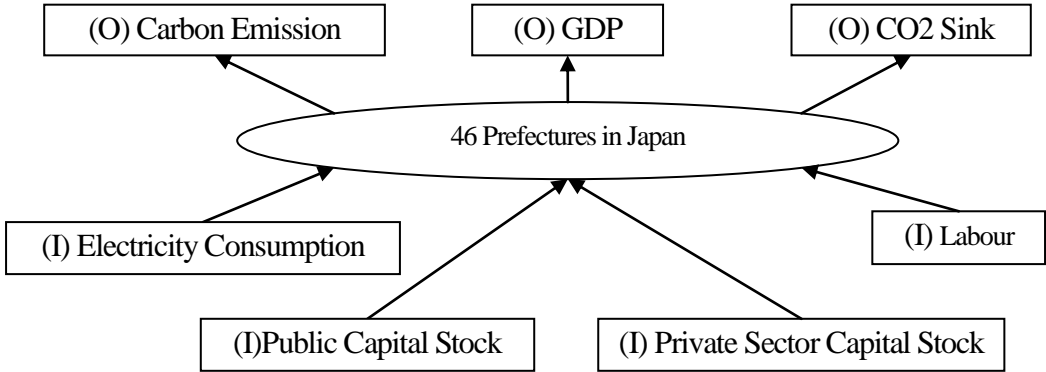


Figure 7 Inputs and Outputs of Energy-Environment-Economic efficiency

- 4Inputs:
 - (I) Electricity Consumption in prefecture (Giga Watt hour / year) (2008)
 - (I) Public capital stock in prefecture (million yen) (2008)
 - (I) Private-sector capital stock in prefecture (million yen) (2008)
 - (I) Labour in prefecture (2005)

- 3Outputs:

(O) GDP in prefecture (million yen / year) (2008)

(O) Carbon emission in prefecture (inverse number) (Kilo Ton / year) (2008)

(O) CO2 sink in prefecture (Ton / year) (2000)

An explanation for each inputs and outputs are as follow.

(I) Electricity Consumption in prefecture (Giga Watt hour / year) (2008) (EC hereafter)

This dataset was estimated from statistical report on energy consumption, and inter-industry relations table. It was estimated from energy consumption basic unit for each industry and sector. An objective sectors are industrial sector, consumer and service sector, consumer and residential sector, household car sector. On the other hands, Primary energy supply sector, energy conversion sector, traffic and cargo sector are eliminated, that is difficult to consider a regional belongingness.

This datasets even account for consequential (implicit) energy consumption when one prefecture is supplied from other prefecture, in order to appreciate “pseudo-energy saving”.

[Data source:”statistical report on energy consumption for each prefecture”, and “statistics report on comprehensive strategy for energy consumption and environment (2008)”, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry in Japan] (see Figure A1-A4)

(I) Public Capital Stock in prefecture (million yen) (2008) (PCS hereafter)

This dataset is based on traffic field, national conservation field, life field, educational field, industry field. [Data source: Economic and Fiscal model for Prefecture, Cabinet Office, Government of Japan, http://www5.cao.go.jp/keizai3/pref_model.html]

(I) Private Sector capital stock in prefecture (million yen) (2008) (PSCS hereafter)

This dataset is based on agriculture, forestry and fisheries industry, mining industry, construction industry, manufacturing industry, wholesale and retail trade, finance, insurance and real estate industry, transportation and communication industry, utility industry, service industry. [Data source: Economic and Fiscal model for Prefecture, Cabinet Office, Government of Japan, http://www5.cao.go.jp/keizai3/pref_model.html]

(I) Labour in prefecture (2005)

This dataset is based on “Census Return 2005”. [Data source: Statistics Bureau, Ministry of internal affairs and communication, <http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001036794&cycode=0>]

(O) GDP in prefecture (million yen / year) (2008)

This data is based on “National Accounts of Japan”. [Data source: Economic and Fiscal model for Prefecture, Cabinet Office, Government of Japan, http://www5.cao.go.jp/keizai3/pref_model.html]

(O) Carbon Emission in prefecture (inverse number) (Mega Ton / year) (2008) (CE hereafter)

This dataset was estimated from statistical report on energy consumption, and inter-industry relations table. It was estimated from carbon emission basic unit for each industry and sector. An objective sectors are industrial sector, consumer and service sector, consumer and residential sector, household car sector. On the other hands, Primary energy supply sector, energy conversion sector, traffic and cargo sector are eliminated, it is difficult to consider a regional belongingness.

This datasets even account for consequential (implicit) carbon emission when one prefecture is supplied from other prefecture, in order to appreciate ”pseudo-emissions reduction”.

[Data source:”statistical report on energy consumption for each prefecture”, and “statistics report on comprehensive strategy for energy consumption and environment (2008)”, Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry]

(O) CO2 Sink in prefecture (Ton / year) (2000) (Sink hereafter)

This dataset was estimated from “Land-Use, Land Use Change, and Forestry (IPCC 2000)”, and carbon sink basic unit for needle leaf tree (artificial forest), broad-leaf tree(artificial forest), needle leaf tree (natural forest), broad-leaf tree (natural forest).

[Data source: Sugihara. h., et al. “carbon pool of Japanese islands”, Studies in Regional Policy (Development Bank of Japan), Vol.11, pp.1-49, 2004]

In our application, we first applied the SE-CCR-I model, while next the results were used to determine the CCR-I and DFM projections. Additionally, we applied the PA-DFM model. Finally, these various results were mutually compared.

5.2 Efficiency evaluation based on the SE-CCR-I model

The efficiency evaluation result for the 46 prefectures based on the SE-CCR-I model is given in Figure 8. From Figure 8, it can be seen that Tottori (1.523), Kochi (1.251), Iwate (1.222), Hokkaido (1.146), and Shimane (1.139) are top 5 efficiency prefectures. On the other hand, Yamaguchi (0.875), Niigata (0.846), Wakayama (0.832), Ibaraki (0.808), and Ehime (0.787) are low efficiency.

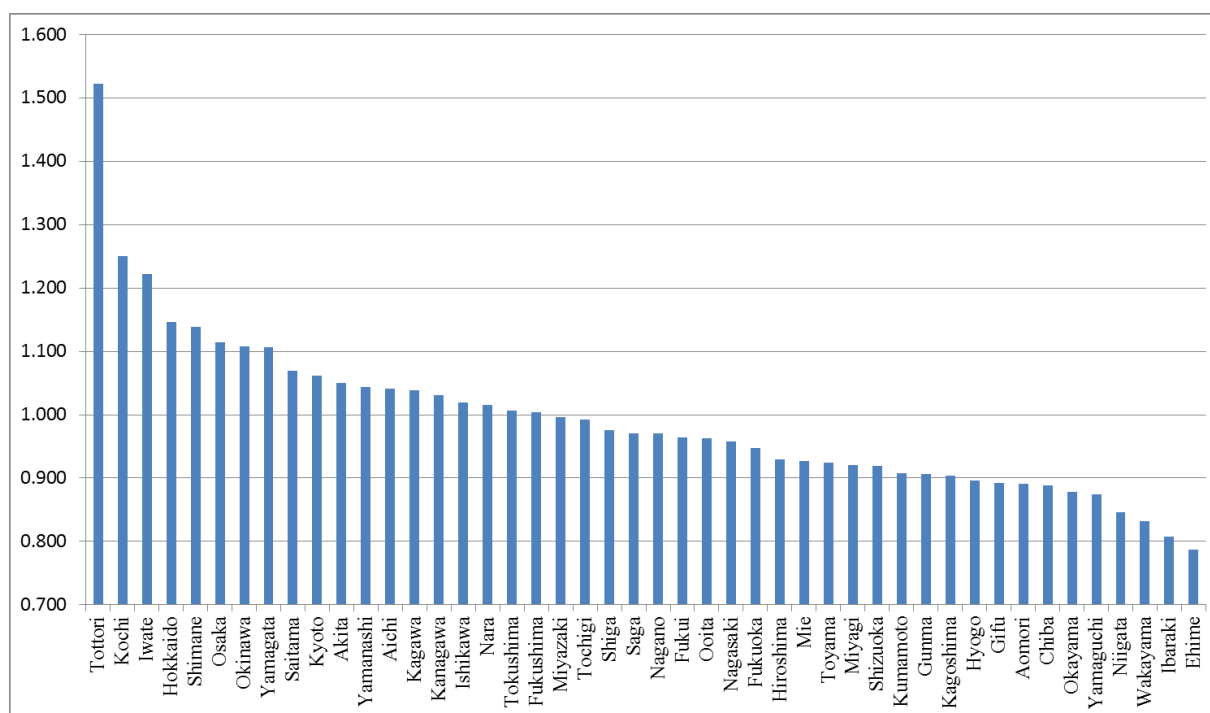


Figure 8 Efficiency score based on the CCR model

5.3 Efficiency improvement projection based on the CCR and DFM models

The efficiency improvement projection results based on the CCR and DFM model for inefficient prefectures are presented in Table 2-A and 2-B.

In Table 2, it appears that the empirical ratios of change in the DFM projection are smaller than those in the CCR projection, as was expected. In Table 2, this particularly applies to Miyagi, Ibaraki, Chiba, Niigata, Gifu, Wakayama, Hiroshima, Ehime, and Kagoshima which are apparently non-slack type (i.e. s^{-**} and s^{+**} are zero) prefectures. The DFM projection involves both input reduction and output increase, and, clearly, the DFM projection does not involve a uniform ratio, because this model looks for the optimal input reduction (i.e., the shortest distance to the frontier, or distance friction minimization).

For instance, the CCR projection shows that Wakayama should reduce the Public Capital Stock (PCS) and Electricity Consumption (EC) by 16.8%, Private Sector Capital Stock (PSCS) by 27.1%, Labour by 17.2%, in order to become efficient.

On the other hand, the DFM results show that a reduction in the Electricity Consumption (EC) of 15.9%, and an increase in the GDP of 13.4% are required to become efficient. Apart from the practicality of such a solution, the models show clearly that a different – and perhaps more efficient – solution is available than the standard CCR projection to reach the efficiency frontier.

Table 2-A Direct efficiency-improvement projection results of the CCR and DFM model

DMU	Score	CCR model		DFM model		DMU	Score	CCR model		DFM model	
		Score(θ^{**})		Score(θ^{**})				Score(θ^{**})		Score(θ^{**})	
		Difference	%	Difference	%			Difference	%	Difference	%
I/O	Data			$d_{io}^{x^* - s^{***}}$	$d_{io}^{y^* + s^{***}}$	I/O	Data			$d_{io}^{x^* - s^{***}}$	$d_{io}^{y^* + s^{***}}$
Aomori	0.891	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Toyama	0.924	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	10732022	-1171609.7	-10.9%	0.0	0.0%	(I)PCS	9211105	-2759422.1	-30.0%	-2594792.2	-28.2%
(I)PSCS	10518020	-1148247.3	-10.9%	-702660.8	-6.7%	(I)PSCS	15059522	-3676856.7	-24.4%	-3151419.8	-20.9%
(I)Labour	685401	-74824.9	-10.9%	0.0	0.0%	(I)Labour	578051	-43718.6	-7.6%	-22718.4	-3.9%
(I)EC	11271	-2181.0	-19.4%	-1277.2	-11.3%	(I)EC	14153	-3850.7	-27.2%	-3407.5	-24.1%
(O)GDP	4605409	0.0	0.0%	308873.7	6.7%	(O)GDP	4903120	0.0	0.0%	221166.2	4.5%
(O)Sink	968060	0.0	0.0%	0.0	0.0%	(O)Sink	349591	0.0	0.0%	0.0	0.0%
(O)CE	0.326862	0.133641	40.9%	0.171649	52.5%	(O)CE	0.425568	0.0	0.0%	0.0	0.0%
Miyagi	0.920	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Fukui	0.963	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	13658142	-3316480.2	-24.3%	0.0	0.0%	(I)PCS	7091840	-721418.0	-10.2%	-661788.0	-9.3%
(I)PSCS	19188273	-1533715.7	-8.0%	-1462849.9	-7.6%	(I)PSCS	10521645	-3093029.4	-29.4%	-2902712.8	-27.6%
(I)Labour	1107773	-88544.1	-8.0%	0.0	0.0%	(I)Labour	423959	-15501.5	-3.7%	-7895.1	-1.9%
(I)EC	20022	-4108.4	-20.5%	0.0	0.0%	(I)EC	8713	-1435.5	-16.5%	-1275.0	-14.6%
(O)GDP	8784591	0.0	0.0%	377924.4	4.3%	(O)GDP	3281193	0.0	0.0%	80107.8	2.4%
(O)Sink	639033	0.0	0.0%	0.0	0.0%	(O)Sink	477053	0.0	0.0%	0.0	0.0%
(O)CE	0.231984	0.0	0.0%	0.0	0.0%	(O)CE	0.613414	0.0	0.0%	0.0	0.0%
Ibaraki	0.808	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Nagano	0.970	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	14120110	-3575961.7	-25.3%	0.0	0.0%	(I)PCS	14863403	-439698.2	-3.0%	0.0	0.0%
(I)PSCS	33377367	-6407810.5	-19.2%	0.0	0.0%	(I)PSCS	20632845	-610373.3	-3.0%	-621218.5	-3.0%
(I)Labour	1461560	-280591.3	-19.2%	-212407.4	-14.5%	(I)Labour	1150880	-34046.0	-3.0%	0.0	0.0%
(I)EC	28799	-6217.4	-21.6%	0.0	0.0%	(I)EC	18246	-643.6	-3.5%	-298.4	-1.6%
(O)GDP	11878275	0.0	0.0%	1287488.6	10.8%	(O)GDP	9302494	0.0	0.0%	161113.7	1.7%
(O)Sink	301037	0.0	0.0%	0.0	0.0%	(O)Sink	1579136	0.0	0.0%	0.0	0.0%
(O)CE	0.119823	0.0	0.0%	0.0	0.0%	(O)CE	0.300947	0.0	4.8%	0.0	2.5%
Tochigi	0.993	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Gifu	0.892	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	9295104	-66792.9	-0.7%	-33516.9	-0.4%	(I)PCS	12700041	-1366078.2	-10.8%	-1369654.0	-10.8%
(I)PSCS	21274879	-785008.2	-3.7%	-679940.7	-3.2%	(I)PSCS	18233151	-1961246.4	-10.8%	0.0	0.0%
(I)Labour	1017139	-106915.1	-10.5%	-102715.5	-10.1%	(I)Labour	1071054	-115207.8	-10.8%	0.0	0.0%
(I)EC	20280	-2615.8	-12.9%	-2527.1	-12.5%	(I)EC	17849	-3345.7	-18.8%	0.0	0.0%
(O)GDP	8707718	0.0	0.0%	44297.5	0.5%	(O)GDP	7672710	0.0	0.0%	597766.4	7.8%
(O)Sink	533297	0.0	0.0%	0.0	0.0%	(O)Sink	1279322	0.0	0.0%	0.0	0.0%
(O)CE	0.284151	0.0	0.0%	0.0	0.0%	(O)CE	0.291415	0.070532	24.2%	0.0	0.0%
Gunma	0.906	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Shizuoka	0.919	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	9625053	-907341.8	-9.4%	-476112.1	-4.9%	(I)PCS	17681202	-1435519.6	-8.1%	-987174.3	-5.6%
(I)PSCS	21035503	-3499892.3	-16.6%	-2138304.5	-10.2%	(I)PSCS	40408182	-3280701.1	-8.1%	0.0	0.0%
(I)Labour	1015579	-209721.5	-20.7%	-155298.8	-15.3%	(I)Labour	1990647	-161618.7	-8.1%	-800.5	0.0%
(I)EC	18925	-3714.2	-19.6%	-2565.4	-13.6%	(I)EC	40274	-9121.1	-22.7%	-4698.6	-11.7%
(O)GDP	7472226	0.0	0.0%	574058.7	7.7%	(O)GDP	17098302	0.0	0.0%	853754.8	5.0%
(O)Sink	627936	0.0	0.0%	0.0	0.0%	(O)Sink	776916	0.0	0.0%	0.0	0.0%
(O)CE	0.315539	0.0	0.0%	0.0	0.0%	(O)CE	0.139457	0.065113	46.7%	0.0	32.9%
Chiba	0.888	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Mie	0.926	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	19665495	-2199864.6	-11.2%	0.0	0.0%	(I)PCS	10933145	-1581755.9	-14.5%	-1328579.4	-12.2%
(I)PSCS	46010190	-5146892.6	-11.2%	-4383291.8	-9.5%	(I)PSCS	22823511	-3544210.3	-15.5%	-2727328.1	-11.9%
(I)Labour	2948581	-329840.6	-11.2%	0.0	0.0%	(I)Labour	922622	-67860.0	-7.4%	-35225.4	-3.8%
(I)EC	46706	-7773.3	-16.6%	0.0	0.0%	(I)EC	23801	-7178.5	-30.2%	-6491.0	-27.3%
(O)GDP	20555275	0.0	0.0%	1226859.5	6.0%	(O)GDP	8272522	0.0	0.0%	344041.7	4.2%
(O)Sink	252309	0.0	0.0%	0.0	0.0%	(O)Sink	591905	0.0	0.0%	0.0	0.0%
(O)CE	0.064522	0.093817	145.4%	0.0	0.0%	(O)CE	0.204087	0.0	0.0%	0.0	0.0%
Niigata	0.846	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Shiga	0.975	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	20853071	-8932395.9	-42.8%	0.0	0.0%	(I)PCS	7789565	-412551.5	-5.3%	-347713.2	-4.5%
(I)PSCS	25666267	-5483606.2	-21.4%	0.0	0.0%	(I)PSCS	15773767	-1090435.9	-6.9%	-883496.6	-5.6%
(I)Labour	1225575	-188578.4	-15.4%	0.0	0.0%	(I)Labour	680478	-16750.3	-2.5%	-8479.5	-1.2%
(I)EC	20027	-3081.5	-15.4%	-2899.9	-14.5%	(I)EC	16598	-3490.0	-21.0%	-3315.4	-20.0%
(O)GDP	9221176	0.0	0.0%	841052.8	9.1%	(O)GDP	6284265	0.0	0.0%	87104.6	1.4%
(O)Sink	1139378	0.0	0.0%	0.0	0.0%	(O)Sink	316275	0.0	0.0%	0.0	0.0%
(O)CE	0.215737	0.037802	17.5%	0.0	0.0%	(O)CE	0.436405	0.0	0.0%	0.0	0.0%

Table 2-B Direct efficiency-improvement projection results of the CCR and DFM model

DMU	Score	CCR model		DFM model		DMU	Score	CCR model		DFM model	
		Score(θ^{**})		Score(θ^{**})				Score(θ^{**})		Score(θ^{**})	
		Difference	%	Difference	%			Difference	%	Difference	%
I/O	Data			d_{io}^{+*}	$-s^{-**}$	d_{io}^{+*}	$-s^{-**}$	d_{io}^{+*}	$-s^{-**}$	d_{io}^{+*}	$-s^{-**}$
Hyogo	0.896	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Saga	0.971	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	24699466	-3439230.6	-13.9%	-2384394.7	-9.7%	(I)PCS	7583269	-673565.3	-8.9%	-371101.3	-4.9%
(I)PSCS	49635353	-5146637.7	-10.4%	-4649364.2	-9.4%	(I)PSCS	8250120	-1548664.6	-18.8%	-1391100.3	-16.9%
(I)Labour	2553965	-264818.0	-10.4%	0.0	0.0%	(I)Labour	423379	-12343.0	-2.9%	0.0	0.0%
(I)EC	55286	-17387.5	-31.5%	-15246.8	-27.6%	(I)EC	6974	-203.3	-2.9%	-167.3	-2.4%
(O)GDP	21358429	0.0	0.0%	1187788.4	5.6%	(O)GDP	3040815	0.0	0.0%	59363.9	2.0%
(O)Sink	866310	0.0	0.0%	0.0	0.0%	(O)Sink	181119	296539.5	163.7%	344414.4	190.2%
(O)CE	0.075005	0.141898	189.2%	-0.396532	-528.7%	(O)CE	0.802403	0.0	0.0%	0.0	0.0%
Wakayama	0.832	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Nagasaki	0.958	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	6762620	-1135355.6	-16.8%	0.0	0.0%	(I)PCS	9499878	-400988.6	-4.2%	0.0	0.0%
(I)PSCS	9499124	-2575744.6	-27.1%	0.0	0.0%	(I)PSCS	10958889	-835104.1	-7.6%	-544287.5	-5.0%
(I)Labour	478478	-82332.0	-17.2%	0.0	0.0%	(I)Labour	679847	-93310.3	-13.7%	-73759.7	-10.8%
(I)EC	7277	-1221.7	-16.8%	-1156.9	-15.9%	(I)EC	8597	-362.9	-4.2%	-238.2	-2.8%
(O)GDP	3087294	0.0	0.0%	413744.0	13.4%	(O)GDP	4533914	0.0	0.0%	118753.0	2.6%
(O)Sink	570435	0.0	0.0%	0.0	0.0%	(O)Sink	360161	430553.3	119.5%	488355.8	135.6%
(O)CE	0.359233	0.0	0.0%	0.0	0.0%	(O)CE	0.553778	0.0	0.0%	0.0	0.0%
Okayama	0.879	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Kumamoto	0.907	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	11266399	-1422707.9	-12.6%	-1011768.7	-9.0%	(I)PCS	11247874	-1044007.2	-9.3%	0.0	0.0%
(I)PSCS	20835164	-2628158.5	-12.6%	-1302249.3	-6.3%	(I)PSCS	13070377	-1213168.6	-9.3%	-726215.9	-5.6%
(I)Labour	932588	-113263.1	-12.2%	-60292.9	-6.5%	(I)Labour	873871	-81111.1	-9.3%	0.0	0.0%
(I)EC	25189	-9332.1	-37.1%	-8216.3	-32.6%	(I)EC	13667	-1976.5	-14.5%	-1023.3	-7.5%
(O)GDP	7811423	0.0	0.0%	558425.7	7.1%	(O)GDP	6117562	0.0	0.0%	325087.5	5.3%
(O)Sink	732723	0.0	0.0%	0.0	0.0%	(O)Sink	731157	0.0	0.0%	0.0	0.0%
(O)CE	0.096205	0.0	0.0%	0.0	0.0%	(O)CE	0.389481	0.0	8.8%	0.1	16.3%
Hiroshima	0.929	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Ooita	0.963	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	15114800	-1069444.7	-7.1%	0.0	0.0%	(I)PCS	8582290	-947965.9	-11.1%	-894519.0	-10.4%
(I)PSCS	28830050	-2039864.5	-7.1%	0.0	0.0%	(I)PSCS	11380572	-426754.1	-3.8%	0.0	0.0%
(I)Labour	1398474	-98948.8	-7.1%	-81585.0	-5.8%	(I)Labour	571645	-21435.8	-3.8%	-14597.0	-2.6%
(I)EC	27329	-4853.8	-17.8%	0.0	0.0%	(I)EC	13931	-4294.3	-30.8%	-3879.8	-27.9%
(O)GDP	12274204	0.0	0.0%	492733.4	4.0%	(O)GDP	4894415	0.0	0.0%	104089.9	2.1%
(O)Sink	923435	0.0	0.0%	0.0	0.0%	(O)Sink	720082	0.0	0.0%	0.0	0.0%
(O)CE	0.082477	0.016455	20.0%	0.0	0.0%	(O)CE	0.173781	0.0	0.0%	0.0	0.0%
Yamaguchi	0.875	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Miyazaki	0.996	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	9256570	-1300669.0	-14.1%	-975710.5	-10.5%	(I)PCS	8742928	-38107.7	-0.4%	0.0	0.0%
(I)PSCS	18608965	-5057676.7	-27.2%	-4009187.5	-21.5%	(I)PSCS	8094921	-35283.2	-0.4%	-20591.0	-0.3%
(I)Labour	716331	-89776.5	-12.5%	-47889.2	-6.7%	(I)Labour	552738	-6056.4	-1.1%	-4997.3	-0.9%
(I)EC	26249	-14376.1	-54.8%	-13493.8	-51.4%	(I)EC	9050	-1015.8	-11.2%	-998.0	-11.0%
(O)GDP	5845895	0.0	0.0%	441586.3	7.6%	(O)GDP	3841607	0.0	0.0%	10546.1	0.3%
(O)Sink	655972	0.0	0.0%	0.0	0.0%	(O)Sink	960137	0.0	0.0%	0.0	0.0%
(O)CE	0.121294	0.0	0.0%	0.0	0.0%	(O)CE	0.531452	0.0	0.0%	0.0	0.0%
Ehime	0.787	$\theta^{**}=1.000$		$\theta^{**}=1.000$		Kagoshima	0.904	$\theta^{**}=1.000$		$\theta^{**}=1.000$	
(I)PCS	9560539	-2501007.2	-26.2%	0.0	0.0%	(I)PCS	13341705	-2363174.7	-17.7%	0.0	0.0%
(I)PSCS	13786650	-2931244.6	-21.3%	0.0	0.0%	(I)PSCS	12068350	-1163215.3	-9.6%	-975068.1	-8.1%
(I)Labour	679915	-144559.9	-21.3%	-108588.3	-16.0%	(I)Labour	809835	-85737.9	-10.6%	0.0	0.0%
(I)EC	16634	-7119.4	-42.8%	0.0	0.0%	(I)EC	11925	-1149.4	-9.6%	0.0	0.0%
(O)GDP	4802104	0.0	0.0%	633451.6	13.2%	(O)GDP	5513307	0.0	0.0%	303122.4	5.5%
(O)Sink	638878	0.0	0.0%	0.0	0.0%	(O)Sink	924080	0.0	0.0%	0.0	0.0%
(O)CE	0.258737	0.0	0.0%	0.0	0.0%	(O)CE	0.433027	0.1	16.0%	0.0	0.0%
Fukuoka	0.948	$\theta^{**}=1.000$		$\theta^{**}=1.000$							
(I)PCS	21607487	-3022791.2	-14.0%	-1730342.2	-8.0%						
(I)PSCS	39587288	-2060593.0	-5.2%	-1710059.7	-4.3%						
(I)Labour	2297154	-119571.2	-5.2%	0.0	0.0%						
(I)EC	38585	-4861.5	-12.6%	-3776.0	-9.8%						
(O)GDP	19010098	0.0	0.0%	507976.3	2.7%						
(O)Sink	365555	318350.0	87.1%	471102.4	128.9%						
(O)CE	0.099241	0.346673	349.3%	0.443581	447.0%						

5.4 Efficiency improvement projection of the PA-DFM model

In this subsection, we will use as an inefficient reference prefecture Wakayama, and present an efficiency improvement projection result based on the PA-DFM model. We assume that the OAP uses steps from 0.0 to 1.0 at intervals of 0.1. Next, the input reduction values and the output increase values based on the PA-DFM model are calculated in Figure 9.

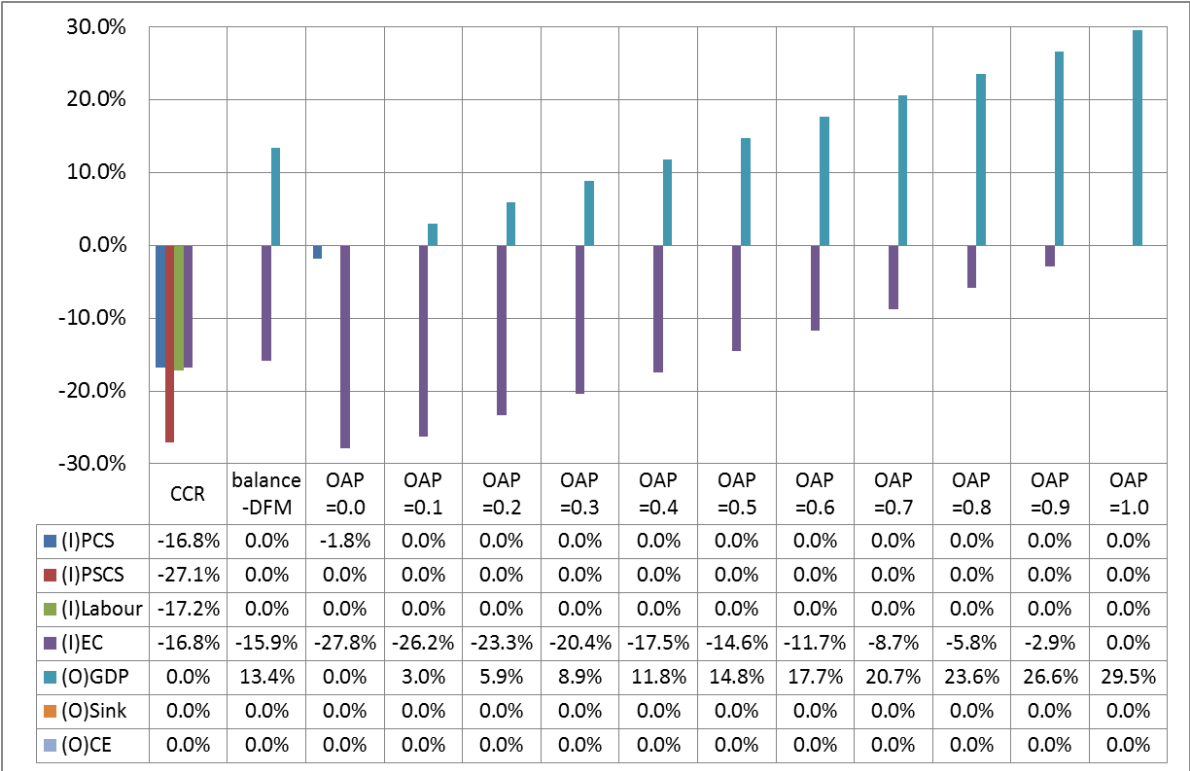


Figure 9 Efficiency improvement projection results based on the PA-DFM (Wakayama)

These results show that, if the prefecture implements an efficiency improvement plan with a OAP amounting to 0.3 (i.e. 30% of the total efficiency gap is allocated for output and 70% of the total efficiency gap is allocated for input), a reduction in the EC of 20.4 % and an increase in GDP of 8.9% are required, and then the efficiency score improved 1.000. Furthermore, the results of a plan with a OAP of 0.0 (i.e. 100% of the total efficiency gap is allocated for input), a reduction in the EC of 27.8 % and in the SCS of 1.8% are required, and then the efficiency score improved 1.000.

6. Conclusion

In this paper we have presented a new methodology, the PA-DFM model. The new model could be adapted a realistic circumstance and requirement in an efficiency improvement projection.

These results may offer a meaningful contribution for the decision making and planning for the efficiency improvement of Energy-Environment-Economic for each prefecture in Japan. And this

new model may thus become a policy instrument that may have great added value for the decision making and planning. For example, an agreement for Energy-Environment-Economic balance policy; all inefficient prefectures have to completely improve an efficiency (reach to score 1.000), but an allocation balance of input-output improvement can freely be set based on each condition for each prefecture. This framework might be a new concept like “Kyoto Protocol” for each prefecture in Japan.

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Appendix

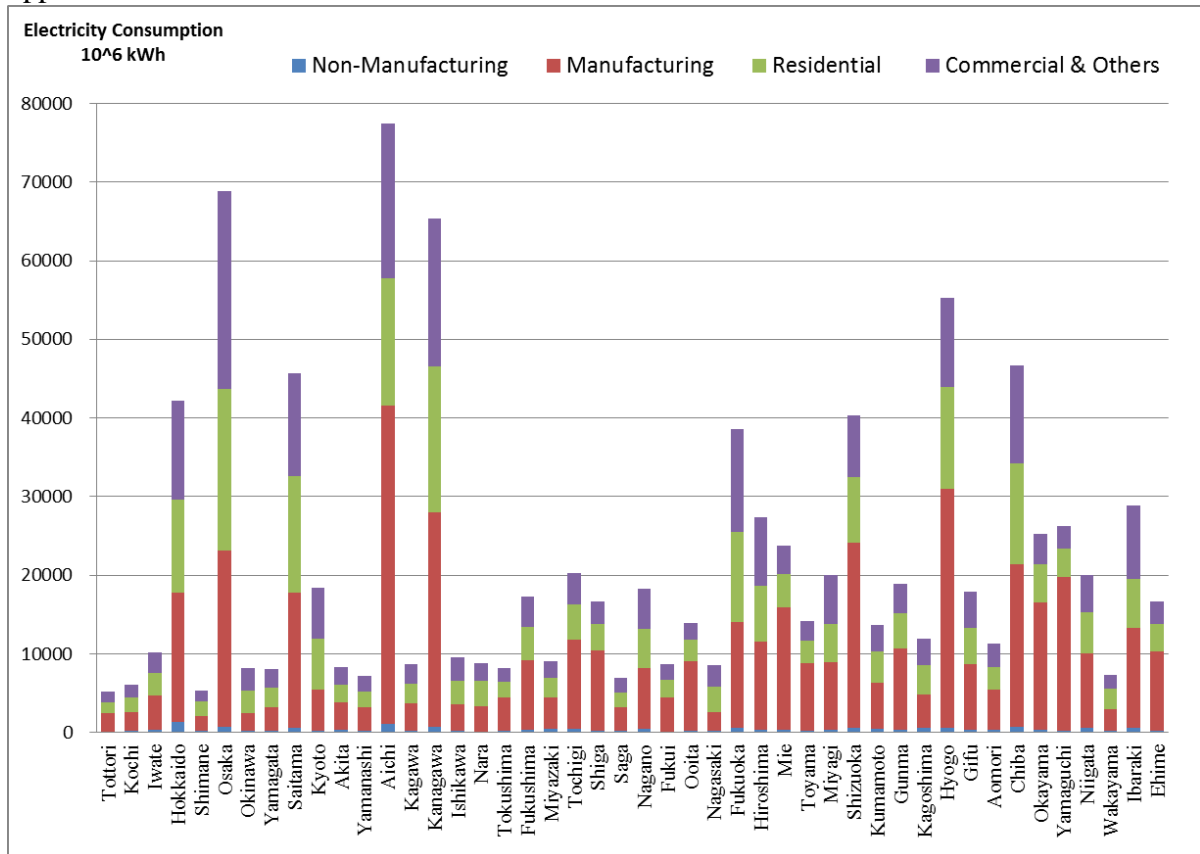


Figure-A1 Electricity consumption of sectors (large classification) in prefecture (score ordered)

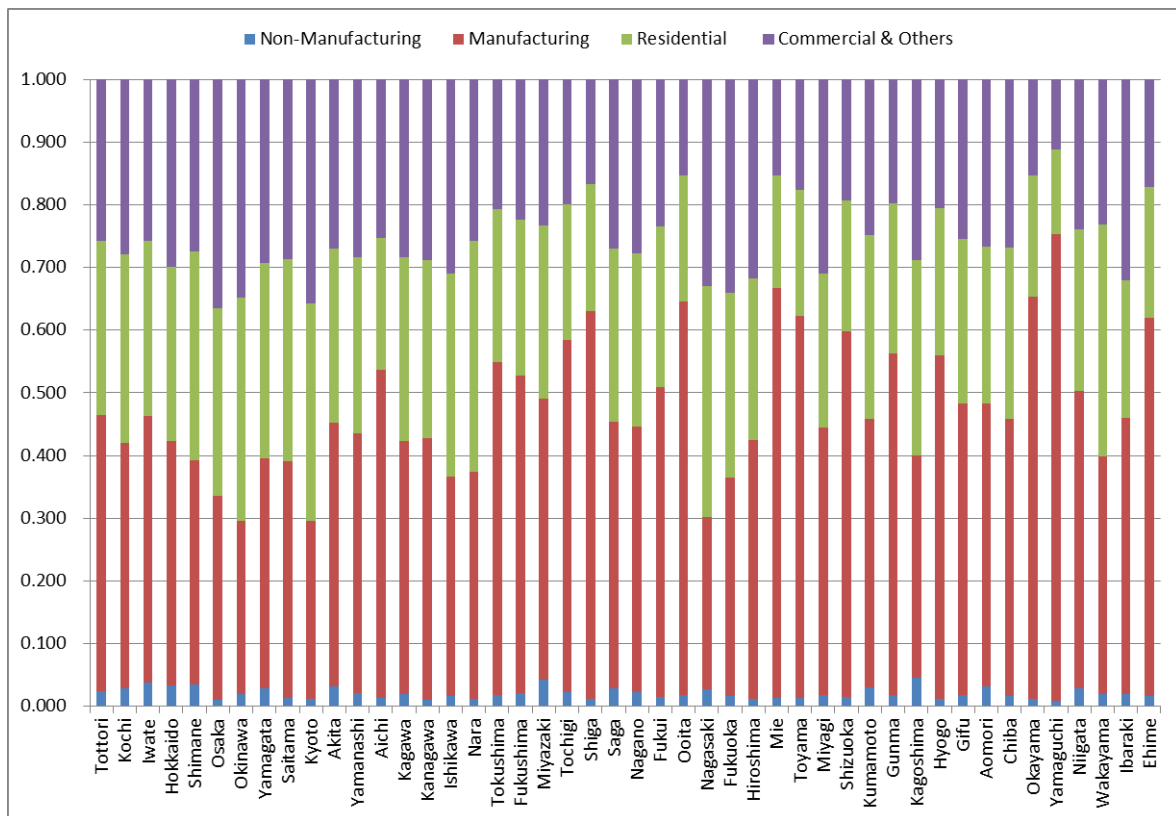


Figure-A2 Electricity consumption share of sectors (large classification) in prefecture (score ordered)

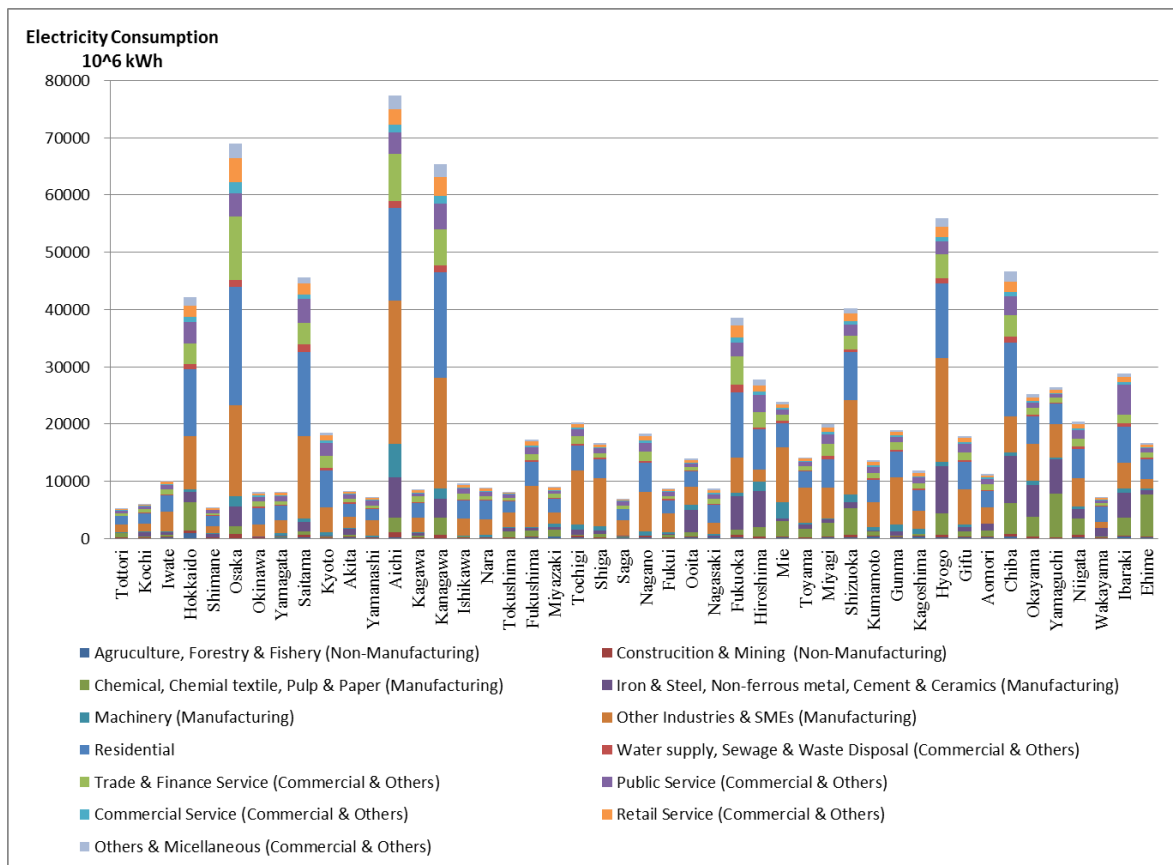


Figure-A3 Electricity consumption of sectors (small classification) in prefecture (score ordered)



Figure-A4 Electricity consumption share of sectors (small classification) in prefecture (score ordered)