



DEA radial measurement for environmental assessment: A comparative study between Japanese chemical and pharmaceutical firms



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HIGHLIGHTS

- The type of RTS is measured under natural disposability.
- The type of DTS is measured under managerial disposability.
- 50% of chemical firms belong to decreasing RTS.
- Their 59.5% belong to increasing DTS.
- New environmental technology is necessary.

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ABSTRACT

Climate change and various pollutants have been influencing our societies and economies. Recently, many individuals, firms and public entities (e.g., the United Nations) are interested in environmental protection (e.g., reduction of CO₂ emission). This study discusses a use of DEA (Data Envelopment Analysis) to measure unified (operational and environmental) efficiency by considering energy utilization and environmental protection. A DEA model used in this study belongs to the radial measurement whose frontier is shaped by the Debreu–Farrell type of efficiency measure. In applying DEA to environmental assessment, it is necessary for us to classify outputs into desirable and undesirable categories because private and public entities usually produce the two types of outputs as a result of their economic activities. After the classification, it is necessary for us to unify between desirable and undesirable outputs and then to incorporate the concept of natural and managerial disposability into DEA. Furthermore, this study theoretically explores how to measure the type of RTS (Returns to Scale) under natural disposability and how to measure the type of DTS (Damages to Scale) under managerial disposability. Such scale measures are quantitatively explored under two disposability concepts. As an illustrative application, this study compares between Japanese chemical and pharmaceutical firms in terms of their unified efficiency measures and the type of RTS/DTS. This study finds two empirical implications. One of the two implications is that approximately 50% of firms in the two groups belong to decreasing RTS. Therefore, it is recommended that they should reduce their corporate sizes to enhance the operational performance. The other implication is that 59.5% of chemical firms, belonging to increasing DTS, should reduce their sizes to reduce their environmental performance. Alternatively, this study recommends that they should introduce new environmental technology to reduce an amount of their undesirable outputs. The technology innovation on undesirable outputs has more practicality than the scale decrease for the chemical firms.

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1. Introduction

Climate change and global warming become a major policy issue in the world. It implies an increase in average global temperature

regarding air, sea and land on the earth. Natural events and human activities, including all industrial and economic activities, contribute to an increase in average global temperature. The climate change is primarily caused by an increase in “greenhouse” gases such as carbon dioxide (CO₂), sulfur dioxide (SO₂) and methane (CH₄).

To combat the climate change in the world, many previous studies proposed a use of DEA (Data Envelopment Analysis) as a methodology for environmental assessment. See, for example,

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[1–13]² and many other articles on DEA in the past decade. As discussed in these studies, DEA was originally developed as a methodology to evaluate the economic performance of various organizations in public and private sectors. These previous studies extended a conventional use of DEA to environmental assessment for organizations that produced not only desirable but also undesirable outputs. Their contributions were summarized by the literature review of Zhou et al. [14] that listed more than 100 articles in environment and energy studies. By their research efforts, DEA environmental assessment can serve as a methodology for planning a sustainable society, through the performance evaluation, where DEA can guide an industrial policy regarding how to increase the level of economic prosperity and how to decrease the amount of greenhouse gases, simultaneously.

In the history of DEA environmental assessment, Sueyoshi and Goto [15–17] first proposed non-radial models and then Sueyoshi and Goto [18] proposed radial models because the formers could more easily unify desirable and undesirable outputs than the latter. Sueyoshi and Goto [19–22] extended their non-radial and radial models by linking them to RTS (Returns to Scale) and DTS (Damages to Scale: RTS corresponds to undesirable outputs) within DEA environmental assessment. The approaches measured the type of RTS/DTS by the intercept of a supporting hyperplane on production and environment-oriented possibility sets, respectively. However, desirable and undesirable outputs usually influence each other in the RTS/DTS measurement. Thus, it is necessary for the proposed measurement to consider both the intercept of a supporting hyperplane and the influence from the two types of outputs. This study discusses the radial-based RTS/DTS measurement because no previous research has explored it and then applies it for comparing between Japanese chemical and pharmaceutical firms.

To attain the research objective, this study starts with examining how the radial measurement can measure the unified efficiency of organizations that use inputs to yield both desirable and undesirable outputs. Then, this study discusses how to measure the type of RTS/DTS within the framework of radial measurement. Finally, as an illustrative application, this research compares

between Japanese chemical and pharmaceutical firms by considering their energy utilizations and environmental protections. This type of empirical comparison has been never explored in the previous studies on energy and environment.

The remainder of this study is organized in the following manner. Section 2 reviews strategic and economic concepts, both of which are incorporated into the proposed DEA radial measurement for environmental assessment. The strategic concepts are expressed by natural and managerial disposability. Section 3 discusses how to measure unified (operational and environmental) efficiency. Section 4 extends it to a description on how to measure unified efficiency under natural disposability. The section also discusses on how to measure RTS. Section 5 shifts to our description to unified efficiency under managerial disposability and DTS. The section also compares between RTS and DTS in terms of scale-related corporate strategies. Section 6 describes how the proposed approach is different from the previous research efforts on RTS/DTS. As an illustrative application, Section 7 compares between Japanese chemical and pharmaceutical firms in terms of their unified efficiency measures and the type of RTS/DTS classification. Section 8 summarizes this study along with future research extensions.

2. Strategic and economic concepts

2.1. Weak and strong disposability

Let us consider $X \in R_+^m$ as an input vector, $G \in R_+^s$ as a desirable output vector and $B \in R_+^h$ as an undesirable output vector. These vectors are referred to as “production factors” in this study. Considering both desirable and undesirable output vectors, Färe et al. [23] has specified an output vector as (G, B) . Weak disposability is specified by the following vector notation:

$$P^W(X) = \left\{ (G, B) : G \leq \sum_{j=1}^n G_j \lambda_j, B = \sum_{j=1}^n B_j \lambda_j, X \geq \sum_{j=1}^n X_j \lambda_j, \sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0 (j = 1, \dots, n) \right\},$$

where the subscript (j) stands for the j th DMU (Decision Making Unit, corresponding to an organization in private and public sectors) and λ_j indicates the j th intensity variable ($j = 1, \dots, n$) which is used for connecting production factors. In the specification, desirable outputs are strongly disposable, but undesirable outputs are not. The inequality constraints ($G \leq \sum_{j=1}^n G_j \lambda_j$) reflects the strong disposability where an efficiency frontier locates above all observations in a data space. Meanwhile, the equality constraints ($B = \sum_{j=1}^n B_j \lambda_j$) makes it possible to measure an occurrence of congestion on undesirable outputs.

Strong disposability is specified by the following vector notation on the two output vectors:

$$P^S(X) = \left\{ (G, B) : G \leq \sum_{j=1}^n G_j \lambda_j, B \leq \sum_{j=1}^n B_j \lambda_j, X \geq \sum_{j=1}^n X_j \lambda_j, \sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0 (j = 1, \dots, n) \right\}.$$

The inequality constraints ($B \leq \sum_{j=1}^n B_j \lambda_j$) allow for strong disposability on undesirable outputs.

It is important to note that the previous research [23] has used the constraints $B = \sum_{j=1}^n B_j \lambda_j$ or $B \leq \sum_{j=1}^n B_j \lambda_j$ in order to identify an occurrence of congestion on undesirable outputs. However, this study uses the constraints $B \geq \sum_{j=1}^n B_j \lambda_j$ because we are not interested in the congestion, rather being interested in technology innovation on undesirable outputs.

To explain a rationale regarding why we are not interested in an occurrence of congestion on undesirable outputs, this study prepares Fig. 1 that visually describes the congestion on an undesirable output along with the concept of weak disposability. The

² Dyckhoff and Allen [1] discussed that a non-radial model was useful as an ecological efficiency measure. All production factors were classified by good, natural and bad inputs/outputs. Korhonen and Luptacik [2] started from a conventional radial model, so-called CCR-ratio form and then discussed how to measure ecological efficiency. Kumar [3] discussed a radial model to measure a Malmquist-Luenberger index in a time horizon. The study compared a frontier shift of efficiency frontiers from 1972 to 1992. Liang et al. [4] used a conventional radial model to identify differences in solving an industrial pollution problem in Anhui province of China. Oude Lansink and Bezlepkin [5] used DEA to measure the efficiency of greenhouse firms in the Netherlands over the period 1991–1995, based upon the concept of weak and strong disposability. Pasurka [6], Picazo-Tadeo et al. [7] applied the conventional DEA approach to measure the performance of Spanish producers of ceramic pavements by using the concept of weak and strong disposability. Ramanathan [8] investigated the amount of CO2 emission in developing nations. The study found that Luxembourg, Norway, Sudan, Switzerland and Tanzania were efficient countries, followed by India and Nigeria. Central European countries such as Poland, Romania, Czech Republic, and South Africa belonged to the least efficient group. Wang et al. [9] proposed several efficiency models based on environmental production technology under constant RTS. The study found that the environmental and economic efficiency of China were low and there were comparatively large differences in different areas. Triantis and Otis [10] proposed an approach for benchmark correspondence to examine environmental performance. The pairwise dominance was applied to segregate production plans into multiple groups according to their relative environmental and productive efficiency performance. Zaim [11] measured the environmental performance of manufacturing in US states, examining their Malmquist quantity indexes. Zhou and Ang [12] proposed several DEA models to measure economy-wide energy efficiency performance. As an illustrative example, the study applied the proposed models to measure the energy efficiency performance of 21 OECD countries. Zhou et al. [13] compared the methodology proposed in [12] with two conventional stochastic frontier approaches, using the data set on OECD. The study found that the stochastic frontier approaches had a high discriminating capability in energy efficiency performance measurement at the level that it outperformed DEA.

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