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# DEA (Data Envelopment Analysis) assessment of operational and environmental efficiencies on Japanese regional industries

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ABSTRACT

A balance between industrial pollution and economic growth becomes a major policy issue to attain a sustainable society in the world. To discuss the problem from economics and business perspectives, this study proposes a new use of DEA (Data Envelopment Analysis) as a methodology for unified (operational and environmental) assessment. A unique feature of the proposed approach is that it separates outputs into desirable and undesirable categories. Such separation is important because energy industries usually produce both desirable and undesirable outputs. This study discusses how to unify the two types of outputs under natural and managerial disposability. The proposed DEA approach evaluates various organizations by the three efficiency measures such as OE (Operational Efficiency), UEN (Unified Efficiency under Natural disposability) and UENM (Unified Efficiency under Natural and Managerial disposability). An important feature of UENM is that it separates inputs into two categories and unifies them under the two disposability concepts in addition to the proposed output separation and unification. This study incorporates an amount of capital assets for technology innovation, as one of the two input group, into the measurement of UENM. Then, it compares UENM with the other two efficiency measures. This study is the first research effort in which DEA has an analytical capability to quantify the importance of investment on capital assets for technology innovation. To confirm the practicality of the proposed approach, this study applies the three efficiency measures to a data set regarding manufacturing and non-manufacturing industries of 47 prefectures in Japan. This study empirically confirms the validity of Porter hypothesis in Japanese manufacturing industries, so implying that environmental regulation has been effective for betterment on the performance of Japanese manufacturing industries. Another important finding is that the emission of greenhouse gases is a main source of unified inefficiency in the two groups of industries. Therefore, Japanese industries, examined in this study, need to make their efforts to reduce the greenhouse gas emissions and air pollution substances by investing in capital assets for technology innovation.



## 1. Introduction

After the Great East Japan Earthquake and the nuclear accident at Fukushima Daiichi power plant in March 2011, Japan has been facing a major policy change on its basic energy plan, consequently directing toward more renewable resources and less dependency on nuclear power generation. The Japanese government has begun a new policy discussion on “Basic Energy Plan” regarding a future desirable energy mix. It is widely known that Japan has few energy resources, so depending on import for approximately 95% of its primary energy supply. Even the nuclear generation is considered as part of domestic energy, the energy import dependency is still at 81% as of 2010. See Ref. [1].

Along with the policy shift to a new energy mix after the earthquake in 2011, Japan needs to pay attention to the climate change and global warming in the world. Since the Kyoto Protocol came into effect in 2005, Japanese government promoted environmental policy to reduce GHG (Greenhouse Gas) emissions from a use of fossil fuels. The environmental policy has influenced on Japanese manufacturing industries that are major contributors to the growth of not only its whole economy but also regional economies. Meanwhile, they are the large producers of GHG emissions such as $CO_2$. In 2011, the industry sector accounted for approximately 34% of $CO_2$ emission. That is the largest sector for the amount of $CO_2$ emission, although its share has gradually decreased over time. See Ref. [2].

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**Abbreviation and nomenclature**

| | |
|---|---|
| DMU | Decision Making Unit |
| DEA | Data Envelopment Analysis |
| URS | unrestricted |
| UE | unified efficiency |
| OE | operational efficiency |
| UEN | unified efficiency under natural disposability |
| UEM | unified efficiency under managerial disposability |
| UENM | unified efficiency under natural & managerial disposability |
| GPP | gross prefecture product |
| RTS | returns to scale |
| DTS | damages to scale |
| $L$ | labor index |
| $E$ | energy consumption |
| $K$ | capital index |
| $X$ | a column vector of $m$ inputs |
| $G$ | a column vector of $s$ desirable outputs |
| $B$ | a column vector of $h$ undesirable outputs |
| $d_i^x$ | an unknown slack variable of the $i$-th input |
| $d_r^g$ | an unknown slack variable of the $r$-th desirable output |
| $d_f^b$ | an unknown slack variable of the $f$-th undesirable output |
| $\lambda$ | an unknown column vector of intensity or structural variables |
| $R_i^x$ | a data range related to the $i$-th input, |
| $R_r^g$ | a data range related to the $r$-th desirable output |
| $R_f^b$ | a data range related to the $f$-th undesirable output |

To contribute the development of a sustainable society in Japan, the manufacturing industries need to improve their operational efficiencies and simultaneously to satisfy governmental regulation on industrial pollution. Technology innovation, often arising from environmental constraints, is usually associated with an energy-efficient production system, as discussed by Porter and van der Linde [3]. They stated that corporate efforts for improving the productivity of an entire manufacturing process under environmental regulations resulted in both reducing an energy use and improving productivity. The assertion is often referred to as "Porter Hypothesis" among corporate strategists. The hypothesis implies that regulation on pollution does not jeopardize economic prosperity, rather stimulating technology innovation and producing new environment-conscious products (e.g., electric and hybrid vehicles). The implication is often inconsistent with the view of policy makers and business leaders who believe that no regulation is the best for economic activities.

To measure whether the Porter hypothesis is valid or not in Japanese manufacturing industries, this study considers them as DMUs (Decision Making Units: organizations to be evaluated). Then, this study applies DEA (Data Envelopment Analysis) as a methodology for their performance assessment. See, for example, [4–15] [3] and many other DEA articles published in this journal (Energy) during the past decade. As discussed in these studies, DEA was originally developed as a methodology to evaluate the performance of various organizations in public and private sectors. The previous studies extended a conventional use of DEA to environmental assessment for energy industries and these related pollution issues. See, for example, the research [16] that has discussed the recent development in measuring returns to scale and damages to scale for DEA environmental assessment.

In this study, DEA examines the unified (operational and environmental) performance of manufacturing and non-manufacturing industries of 47 prefectures (local government units in Japan which correspond to states in the United States). It is expected that the examination may reveal whether Japanese manufacturing industries increase their performance measures under governmental regulation, as discussed in the Porter hypothesis. The non-manufacturing industries are used as a comparative alternative of the manufacturing industries in this study. The empirical comparison characterizes the unique features of Japanese manufacturing industries and provides us with information for guiding how to improve their operational and environmental performance. For the research purpose, this study proposes a new use of DEA environmental assessment which combines desirable and undesirable outputs together under two (natural and managerial) disposability concepts related to corporate strategy for environmental protection. The disposability concepts are reorganized to examine an effect of investment in capital assets for technology innovation. An important feature of the technology assessment is that it separates and then unifies inputs into two categories under the two disposability concepts in addition to the output separation and unification. No previous study has explored such a research task. This study is the first research effort to explore it.

The reminder of this paper is organized as follows. Section 2 describes DEA environmental assessment as a methodology for enhancing the operational and environmental performance. Section 3 documents formulations for DEA environmental assessment. Section 4 examines a data set on Japanese manufacturing and non-manufacturing industries. Section 5 summarizes empirical results obtained in this study and discusses economic implications for Japanese industries. Section 6 concludes this study along with future research extensions.

## 2. Underlying concepts

To discuss DEA environmental assessment, this study needs to describe two strategic concepts related to environmental protection [17–20]. One of the two strategic concepts, referred to as "natural disposability", indicates that a DMU decreases the

[3] Bozoglu and Ceyhan [4] applied DEA to examine an energy balance, energy conversion efficiency and farm-level efficiency of trout and sea bass production in the Black Sea of Turkey. Lee [5] proposed an index approach for energy performance for cooling purposes by utilizing both DEA and a cooling degree hour method. Vaninsky [6] discussed a combined use between DEA and a stochastic frontier analysis to predict the upper and lower bound on an efficiency index on national and regional environmental performance during 2010–2030. Yadav et al. [7] applied DEA to evaluate the three efficiency measures regarding electric distribution divisions of an Indian hilly state. Lee and Kung [8] classified Taiwan's 122 buildings into different climate clusters and then applied DEA to assess their energy efficiency measures. Fallahi et al. [9] discussed a DEA-based approach to measure energy efficiency of 32 power electric generation management companies in Iran from 2005 to 2009. Macek and Marik [10] examined controlling systems and their applications to heating, ventilation and air condition systems by utilizing DEA. Lin and Liu [11] applied DEA-based Malmquist measurement to examine an occurrence of energy rebound effect after introducing energy saving. Olanrewaju [12] proposed an integrated approach that combined a logarithmic mean divisia index, an index decomposition analysis method, an artificial neural network and DEA to measure energy efficiency in the Canadian industrial sector from 1990 to 2000. Zhou et al. [13] discussed undesirable output-oriented DEA models with different returns to scale to investigate an amount of $CO_2$ emission of a transport sector throughout China's 30 administrative regions. Khoshnevisan et al. [14] discussed efficient energy utilization in greenhouse cucumber production by using a conventional use of DEA. Khoshnevisan et al. [15] analyzed the energy efficiency of wheat farms in order to separate efficient and inefficient growers and to calculate the wasteful uses of energy by a traditional application of DEA.

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