DEA Environmental Assessment for Social Sustainability on European Nations and North America

(Full Paper Submission)

Yan Yuan
New Mexico Institute of Mining and Technology
yyuan@nmt.edu

Toshiyuki Sueyoshi
New Mexico Institute of Mining and Technology
toshi@nmt.edu

ABSTRACT

To attain social sustainability on economic development and environment protection, this study utilizes Data Envelopment Analysis (DEA) for assessment by incorporating the concept of natural disposability and managerial disposability. The degree of scale efficiency is newly measured under the two disposability concepts within an radial approach. The proposed methodology is applied to strategic planning for nations in North America and European Union. The empirical results indicate that European countries pay more attention to environment protection along with economic recovery. North America countries should reinforce stronger regulation and policy rules to industries for environment protection than the European ones. Technology innovations will continue improving the quality of our sustainability. Consciousness of consumers and individuals should also be enhanced and educated for energy saving and environmental protection.

KEYWORDS: DEA, Scale efficiency, Disposability, Social Sustainability

INTRODUCTION

The United States is an industrial country and has the world's largest national economy, benefiting from an abundance of natural resources and high worker productivity. Accounting for 37% of global military spending and 19% of world GDP, it is the world's foremost economic and military power, a prominent political and cultural force, and a leader in scientific research and technology innovations. Canada is also a developed country and one of the wealthiest in the world, with the tenth highest nominal per capita income globally, and the eighth highest ranking in the Human Development Index. It ranks among the highest in international measurements of government transparency, civil liberties, quality of life, economic freedom, and education. Their industrial developments have been originated from nations in European Union (EU) that has unified member nations in terms of their economic and political developments. It is expected that they belong to a single common market and policy making on economic and environmental developments.
After experiencing financial crises, all industrial countries in North America and EU commit to recover their economies as soon as possible and they maintain the leadership in economic and political positions in the world. Unfortunately, their reality is different from what they have expected before. This study wonders whether the performance of these industrial nations is sustainable in term of their economic and environmental developments after the recovery of recession.

As a methodology to explore the policy question, this study fully utilizes Data Environment Analysis (DEA), or a non-parametric approach, which can measure the performance efficiency of Decision Making Units (DMUs). An important feature of DEA assessment, discussed in this study, is that it classifies outputs to desirable and undesirable categories because DMUs (e.g., nations and companies) produce not only desirables but also undesirable outputs as a result of their economic activities. The “balanced development of economy and environment” is the policy target of every country and our research concern in this study. Thus, DEA assessment can be used to a benchmark approach for the performance measurement on economic and environmental development in nations in North America and EU for their balanced operations. See, for example, Choi et al. (2012), Guo, et al. (2011) and Shi et al. (2010) for their applications of DEA environmental assessment.

The proposed DEA environmental assessment, which incorporates PM2.5 and PM10, as undesirable outputs, discusses two disposability concepts (i.e., natural disposability and managerial disposability) and measures unified (operational and environmental) efficiency and scale efficiency on their economic developments and environmental protections. This type of research has been never explored in the previous DEA environmental assessment. It is easily envisioned that the policy and business implications, obtained in this study, are important for the environmental development of all industrial countries, including the Asian countries.

The remaining structure of this study is as follows: Section 2 discusses disposability concepts to be utilized in this study. Section 3 describes the methodology, or DEA environmental assessment. Section 4 discusses empirical results obtained from the application to industrial nations in North America and EU. Section 5 summarizes policy implications. Finally, Section 6 concludes this study along with future extensions.

CONCEPTS

Natural Disposability for Economic Stability (First priority: operational performance and Second priority: environmental performance): To discuss the unified (operational and environmental) efficiency of DMUs by using DEA environmental assessment, this study needs to mention two strategic concepts related to environmental protection, referred to as “disposability” that implies the inefficiency elimination by attaining an efficiency frontier.

One of the two strategic concepts, referred to as “natural disposability”, is that operational performance is the first priority and environmental performance is the second priority. This type of disposability is discussed within the conventional framework of DEA performance assessment where an inefficient DMU decreases some components of an input vector or maintains at their current level, but increases some components of a desirable output vector. The decrease of the input vector leads to a reduction on undesirable outputs by a limited corporate effort. Therefore, Sueyoshi and Goto (2012a, 2012b) have referred to it as “natural disposability”. An important feature of this type of disposability is that it does not incorporate an occurrence of technology development on undesirable outputs, rather focusing upon a managerial effort to improve the operational performance of each DMU.
Managerial Disposability for Economic Growth (First priority: environmental performance and Second priority: operational performance): The other strategic concept, referred to as “managerial disposability”, has an opposite priority to the natural disposability in the DEA assessment. In the managerial disposability, a DMU increases the amount of inputs so that it can increase the amount of desirable outputs. Here, even if the DMU increases the amount of inputs, the increase can reduce the amount of undesirable outputs by a managerial effort and/or an engineering effort to utilize new production technology that can reduce the amount of CO2 emission. For example, management of a power plant in this disposability concept considers the environmental regulation as a business opportunity that can appeal to consumers as a green generator. This type of strategy has been long supported by corporate strategists in U.S. business schools.

METHODOLOGY

Mathematical symbols to express production factors are summarized as follows:
(a) \( X_j = (X_{1j}, X_{2j}, \ldots, X_{mj})^T > 0 \): a column vector of m inputs of the j-th DMU (j = 1, ..., n),
(b) \( G_j = (g_{1j}, g_{2j}, \ldots, g_{sj})^T > 0 \): a column vector of s desirable outputs of the j-th DMU and
(c) \( B_j = (b_{1j}, b_{2j}, \ldots, b_{nj})^T > 0 \): a column vector of h undesirable outputs of the j-th DMU,
(d) \( d_i^x \geq 0 \): an unknown slack variable of the i-th input (i = 1, ..., m),
(e) \( d_r^g \geq 0 \): an unknown slack variable of the r-th desirable output (r = 1, ..., s),
(f) \( d_f^b \geq 0 \): an unknown slack variable of the f-th undesirable output (f = 1, ..., h),
(g) \( \lambda = (\lambda_1, \ldots, \lambda_n)^T \): an unknown column vector of “intensity” or “structural” variables,
(h) \( R_i^x = (m + s + h)^{-1} \left( \max \left\{ x_{ij} \mid j = 1, \ldots, n \right\} - \min \left\{ x_{ij} \mid j = 1, \ldots, n \right\} \right)^{-1} \): a data range adjustment related to the i-th input (i = 1, ..., m),
(i) \( R_r^g = (m + s + h)^{-1} \left( \max \left\{ g_{rj} \mid j = 1, \ldots, n \right\} - \min \left\{ g_{rj} \mid j = 1, \ldots, n \right\} \right)^{-1} \): a data range adjustment related to the r-th desirable output (r = 1, ..., s) and
(j) \( R_f^b = (m + s + h)^{-1} \left( \max \left\{ b_{fj} \mid j = 1, \ldots, n \right\} - \min \left\{ b_{fj} \mid j = 1, \ldots, n \right\} \right)^{-1} \): a data range adjustment related to the f-th undesirable output (f = 1, ..., h).
(k) \( \varepsilon \): a small number to be prescribed by a DEA user and
(l) \( \zeta \): an unknown inefficiency score to be determined by DEA models.

Disposability Concepts

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 column vectors are referred to as “production factors” in this study. In these column vectors, the subscript (j) is used to stand for the j-th DMU, corresponding to an organization in private and public sectors.
Unified (operational and environmental) production possibility sets to express natural (N) and managerial (M) disposability are specified by the following two types of output vectors and an input vector, respectively:

\[ P^N_v(X) = \left\{ (G, B) : G \leq \sum_{j=1}^{n} G_j \lambda_j, B \geq \sum_{j=1}^{n} B_j \lambda_j, X \geq \sum_{j=1}^{n} X_j \lambda_j, \sum_{j=1}^{n} \lambda_j = 1 & \lambda_j \geq 0 \right\} \]

\[ P^M_v(X) = \left\{ (G, B) : G \leq \sum_{j=1}^{n} G_j \lambda_j, B \geq \sum_{j=1}^{n} B_j \lambda_j, X \leq \sum_{j=1}^{n} X_j \lambda_j, \sum_{j=1}^{n} \lambda_j = 1 & \lambda_j \geq 0 \right\}. \]

\( P^N_v(X) \) stands for the production possibility set under variable RTS (Return to Scale) and \( P^M_v(X) \) is that of variable DTS (Damage to Scale), where the subscript \((v)\) stands for “variable” RTS and DTS. The difference between the two disposability concepts is that production technology under natural disposability has \( X \geq \sum_{j=1}^{n} X_j \lambda_j \). Meanwhile, the managerial disposability has \( X \leq \sum_{j=1}^{n} X_j \lambda_j \). See Sueyoshi and Goto (2012c, 2012d, 2012e, 2012f) for a detailed description on RTS and DTS.

By changing these axiomatic structures to constant RTS and DTS, the production possibility sets become as follows:

\[ P^N_c(X) = \left\{ (G, B) : G \leq \sum_{j=1}^{n} G_j \lambda_j, B \geq \sum_{j=1}^{n} B_j \lambda_j, X \geq \sum_{j=1}^{n} X_j \lambda_j & \lambda_j \geq 0 \right\}, \]

\[ P^M_c(X) = \left\{ (G, B) : G \leq \sum_{j=1}^{n} G_j \lambda_j, B \geq \sum_{j=1}^{n} B_j \lambda_j, X \leq \sum_{j=1}^{n} X_j \lambda_j & \lambda_j \geq 0 \right\}, \]

where the two equations drop \( \sum_{j=1}^{n} \lambda_j = 1 \) to incorporate constant RTS and DTS. The subscript \((c)\) stands for “constant” RTS and DTS.

This study has two research concerns on the four \((2 \times 2)\) cases on the production possibility sets under the two disposability concepts and the type of RTS and DTS. One of the two concerns is that the operational performance is the first priority and the environmental performance is the second one under natural disposability in assessing the level of unified efficiency. In contrast, the managerial disposability has an opposite priority in the assessment, as discussed previously. The other concern is that the difference between variable and constant RTS and DTS measures exists in the condition \( \sum_{j=1}^{n} \lambda_j = 1 \) on the sum of intensity variables. The former measures incorporate the condition in their formulations, but the latter do not have it. It is possible for us to control the magnitude of \( \sum_{j=1}^{n} \lambda_j \) by assigning its upper and lower bounds, so being able to incorporate different conditions on RTS and DTS.

**Unified Efficiency Measures under Natural Disposability (UEN)**

**UEN under Variable RTS (UEN\(_v\))**: Sueyoshi and Goto (e.g., 2012a, 2012b) has proposed the following radial model to measure the unified efficiency of the k-th DMU under natural disposability as well as variable RTS:
Maximize $\xi + \varepsilon (\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b)$

s.t. $\sum_{j=1}^{n} x_{ij} \lambda_j + d_i^x = x_{ik}$ (i = 1, ... , m),

$\sum_{j=1}^{n} g_{rj} \lambda_j - d_r^g - \xi g_{rk} = g_{rk}$ (r = 1, .. , s)

$\sum_{j=1}^{n} b_{fj} \lambda_j + d_f^b + \xi b_{fk} = b_{fk}$ (f = 1, .. , h),

$\sum_{j=1}^{n} \lambda_j = 1$

$\lambda_j \geq 0$ (j = 1, ..., n), $\xi : URS$, $d_i^x \geq 0$ (i = 1, ..., m),

d_r^g \geq 0 (r = 1, ..., s), and $d_f^b \geq 0 (f = 1, ..., h)$.

A unified efficiency score ($UEN_v$) of the k-th DMU under natural disposability is measured by

$$UEN_v = 1 - [\xi^s + \varepsilon (\sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b)]$$

where the inefficiency score and all slack variables are determined on the optimality of Model (1). The equation within the parenthesis is obtained from the optimality of Model (1). The unified efficiency is obtained by subtracting the level of inefficiency from unity. This study sets $\varepsilon$ as 0.0001 for our computation convenience to reduce an influence of slacks. The $\varepsilon$ was considered as a non-Archimedean small number in the DEA history. The selection of $\varepsilon$ may depends on a subjective decision. Therefore, it is easy to think setting $\varepsilon$ to 0. However, in such a case, dual variables may become zero on some factors so that those factors in a data set cannot be fully utilized in Model (1). This is problematic and unacceptable as a computational result of DEA performance assessment. Therefore, this study treats it as a small positive value.

See Sueyoshi and Goto (2012a) for a computational issue related to Model (1) because Model (1) is a nonlinear programming problem.

**$UEN$ under constant RTS ($UEN_C$):** To attain the status of constant RTS, this study drops the condition ($\sum_{j=1}^{n} \lambda_j = 1$) from Model (1) and measure the level of unified efficiency under both natural disposability and constant RTS by

$$UEN^*_C = Equation (2),$$

where the optimal solution is obtained from Model (1) without $\sum_{j=1}^{n} \lambda_j = 1$. The elimination implies constant RTS under the assumption of no influence of undesirable outputs.

**Scale Efficiency under Natural Disposability ($SEN$):** To examine how each DMU carefully manages the operational size under natural disposability, this study measures the degree of its scale efficiency via
\[ SEN^* = UEN_C^* / UEN_V^*. \]  

Since \( UEN^*_C \leq UEN^*_V \), \( SEN^* \) is less than and equals unity. The higher score in \( SEN \) indicates the better scale management under natural disposability.

**Unified Efficiency under Managerial Disposability (UEM)**

Shifting the research interest of this study from natural disposability to managerial disposability, where the first priority is environmental performance and the second priority is operational performance, this study utilizes the following radial model that measures the unified efficiency of the \( k \)-th DMU (e.g., Sueyoshi and Goto, 2012b) under variable DTS:

Maximize \( \xi + \varepsilon ( \sum_{i=1}^{m} R_i^x d_i^x + \sum_{r=1}^{s} R_r^g d_r^g + \sum_{f=1}^{h} R_f^b d_f^b ) \)

subject to \( \sum_{j=1}^{n} x_{ij} \lambda_j - d_{i}^x = x_{ik} \) \( (i = 1, \ldots, m), \)

\( \sum_{j=1}^{n} g_{rj} \lambda_j - d_{r}^g - \xi g_{rk} = g_{rk} \) \( (r = 1, \ldots, s), \)

\( \sum_{j=1}^{n} b_{fj} \lambda_j + d_{f}^b + \xi b_{fk} = b_{fk} \) \( (f = 1, \ldots, h), \)

\( \sum_{j=1}^{n} \lambda_j = 1, \)

\( \lambda_j \geq 0 \) \( (j = 1, \ldots, n), \) \( \xi : URS, \ d_{i}^x \geq 0 \) \( (i = 1, \ldots, m), \)

\( d_{r}^g \geq 0 \) \( (r = 1, \ldots, s), \) \( d_{f}^b \geq 0 \) \( (f = 1, \ldots, h). \)

An important feature of Model (5) is that it changes \(+d_{i}^x\) of Model (1) to \(-d_{i}^x\) in order to attain the status of managerial disposability. A unified efficiency score (UEM) on the \( k \)-th DMU under managerial disposability is measured by Equation (2), or

\[ UEM_V = 1 - [ \xi^* + \varepsilon ( \sum_{i=1}^{m} R_i^x d_i^x^* + \sum_{r=1}^{s} R_r^g d_r^g^* + \sum_{f=1}^{h} R_f^b d_f^b^* ) ], \]  

where the inefficiency score and all slack variables are determined on optimality of Model (5). The equation within the parenthesis, obtained from the optimality of Model (5), indicates the level of unified inefficiency under managerial disposability and variable DTS. The unified efficiency is obtained by subtracting the level of inefficiency from unity.

**UEM under constant DTS (UEM_C):** To attain the status of constant DTS, this study drops the condition \( \sum_{j=1}^{n} \lambda_j = 1 \) from Model (5) and measure the level of its unified efficiency under managerial disposability and constant DTS by

\[ UEM_C^* = \text{Equation (6)}, \]  

where the optimal solution is obtained from Model (5) without \( \sum_{j=1}^{n} \lambda_j = 1 \).
**Scale Efficiency under Managerial Disposability (SEM):** To measure how each DMU carefully manages the operational size under managerial disposability, this study measures the degree of its scale efficiency via

\[ SEM^* = \frac{UEM^*_C}{UEM^*_V} \]

Since \( UEM^*_C \leq UEM^*_V \), \( SEM^* \) is less than and equals unity. The higher score in \( SEM \) indicates the better scale management under managerial disposability.

**Strengths and drawbacks:** Finally, it is important to note that DEA environmental assessment constructs performance measurement on three types of production factors (inputs, desirable and undesirable outputs). The proposed approach has computational tractability by using linear programming. Another advantage of DEA approach is its analytical ability to accommodate multiple production factors without any specification on functional forms. In contrast, the proposed DEA environmental assessment does not have a statistical inference, based upon an asymmetric concern, so that the proposed approach cannot directly apply various statistical tests at the level that we can find in econometrics.

**EMPIRICAL STUDY**

This study obtains a data set from Organization for Economic Co-operation and Development (OECD) library (http://www.oecd-ilibrary.org/). OECD is set up to promote policies that will improve the economic and social well-being of people around the world. This study examines 25 countries in European Union and North America in 2012 because the most updated data of energy and environment is in 2012. The software used for this study is Matlab. This study utilizes two desirable outputs: Gross Domestic Product (GDP) and electricity generation, four undesirable outputs: PM2.5, CO₂, SO₂ and NO₂ and two inputs: total population and total energy supply. Table 1 exhibits the original data used in this study.

<table>
<thead>
<tr>
<th>Country</th>
<th>GDP (US dollars/capita)</th>
<th>Electricity generation (Terawatt hours)</th>
<th>PM2.5 (Thousands Tonnes)</th>
<th>CO₂ (Million Tonnes)</th>
<th>SO₂ (Million Tonnes)</th>
<th>NO₂ (Million Tonnes)</th>
<th>Total population</th>
<th>Total energy supply (Mtoe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>44892.24</td>
<td>64.5</td>
<td>18.49</td>
<td>6733.47</td>
<td>17.23</td>
<td>178.26</td>
<td>8443018</td>
<td>32.9</td>
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<tr>
<td>Belgium</td>
<td>41684.18</td>
<td>77.3</td>
<td>31.68</td>
<td>106659.4</td>
<td>48.02</td>
<td>189.67</td>
<td>11094850</td>
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</tr>
<tr>
<td>Canada</td>
<td>42283.47</td>
<td>645.7</td>
<td>1368.33</td>
<td>550546.6</td>
<td>1287.66</td>
<td>1861.72</td>
<td>34880491</td>
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</tr>
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<td>20.02</td>
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<td>157.92</td>
<td>210.58</td>
<td>10505445</td>
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</tr>
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<td>30.4</td>
<td>22.58</td>
<td>40798.82</td>
<td>12.47</td>
<td>115.41</td>
<td>5580516</td>
<td>17.0</td>
</tr>
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<td>17.08</td>
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<td>70.4</td>
<td>37.45</td>
<td>50733.33</td>
<td>51.99</td>
<td>145.57</td>
<td>5401267</td>
<td>33.5</td>
</tr>
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<td>France</td>
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<td>555.1</td>
<td>180.68</td>
<td>368670.6</td>
<td>232.4</td>
<td>981.55</td>
<td>63409191</td>
<td>251.7</td>
</tr>
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<td>Germany</td>
<td>42730.19</td>
<td>610.9</td>
<td>111.97</td>
<td>821717.7</td>
<td>427.07</td>
<td>1269.26</td>
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<td>Hungary</td>
<td>22494</td>
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<td>30.17</td>
<td>46072.36</td>
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<td>122.41</td>
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<td>4582769</td>
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</table>
The proposed DEA models are applied to measure the degree of UEN and UEM under variable (v) RTS and DTS and constant (c) RTS and DTS along with SEN and SEM of 25 countries in European Union (EU) and North America. Setting $\varepsilon=0.0001$ in the proposed models, all efficiency scores are calculated and summarized in Table 2.

### Table 2 Unified efficiency measures of countries in 2012

<table>
<thead>
<tr>
<th>Country</th>
<th>UENv</th>
<th>UENC</th>
<th>SEN</th>
<th>UEMv</th>
<th>UEMC</th>
<th>SEM</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>0.7238</td>
<td>0.7158</td>
<td>0.9888</td>
<td>0.8398</td>
<td>0.8143</td>
<td>0.9696</td>
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<td>0.5362</td>
<td>0.9274</td>
<td>0.8617</td>
<td>0.8175</td>
<td>0.9488</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>0.7760</td>
<td>0.6829</td>
<td>0.8800</td>
<td>0.7610</td>
<td>0.6677</td>
<td>0.8774</td>
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<td>Denmark</td>
<td>0.5878</td>
<td>0.5512</td>
<td>0.9378</td>
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</tr>
<tr>
<td>Estonia</td>
<td>1.0000</td>
<td>0.6940</td>
<td>0.6940</td>
<td>1.0000</td>
<td>0.6898</td>
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<tr>
<td>Finland</td>
<td>0.6220</td>
<td>0.6218</td>
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</tr>
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<td>0.6523</td>
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<tr>
<td>Ireland</td>
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<td>1.0000</td>
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<td>Netherlands</td>
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<td>1.0000</td>
<td>1.0000</td>
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<td>1.0000</td>
</tr>
<tr>
<td>Norway</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
</tr>
<tr>
<td>Poland</td>
<td>0.4245</td>
<td>0.2875</td>
<td>0.6774</td>
<td>0.7047</td>
<td>0.6015</td>
<td>0.8535</td>
</tr>
<tr>
<td>Portugal</td>
<td>0.4631</td>
<td>0.4279</td>
<td>0.9241</td>
<td>0.9966</td>
<td>0.9743</td>
<td>0.9777</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>0.6031</td>
<td>0.5217</td>
<td>0.8650</td>
<td>0.7898</td>
<td>0.7722</td>
<td>0.9778</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1.0000</td>
<td>0.6876</td>
<td>0.6876</td>
<td>1.0000</td>
<td>0.7901</td>
<td>0.7901</td>
</tr>
<tr>
<td>Spain</td>
<td>0.9552</td>
<td>0.7086</td>
<td>0.7419</td>
<td>1.0000</td>
<td>0.8907</td>
<td>0.8907</td>
</tr>
</tbody>
</table>
Some countries exhibit a high level of efficiency (close to unity) both in UEN and UEM under variable RTS and DTS such as Spain, Estonia, France, Germany, Iceland, Luxembourg, Netherlands, Norway, Slovenia, Sweden, Switzerland, Canada and United States. This indicates that these countries develop balanced economy and environment efficiently. Finland, Ireland and Czech Republic have balanced development in terms of economy and environment, but at an inefficient level of 0.65, 0.75 and 0.77, respectively.

Four countries which are inefficient in UEN but are evaluated as efficient in UEM. The four nations include Portugal (UEN=0.4631 and UEM=1), Hungary (UEN=0.5237 and UEM=1), Italy (UEN=0.7831 and UEM=1) and United Kingdom (UEN=0.9109 and UEM=1). Especially, Portugal and Hungary, which have attained a high level of environmental efficiency, have an economic difficulty. Other countries, which are inefficient in UEN, are evaluated more efficient in UEM, although UEM is still inefficient. Therefore, all countries pay more attention to environment than economy.

The third and sixth columns of Table 2 summarize UEN and UEM under constant RTS and DTS after dropping $\sum_{j=1}^{n} \lambda_j = 1$ in the proposed formulations. Comparing to UENV and UEMV, efficiency scores are decreased in these magnitudes. For example, the UEN of United States, Canada and Italy drastically drop to level of 0.5, Portugal drops to 0.4209. As the worst country at UEN, Poland drops to 0.2875. The UEM of United States and Canada also drop to 0.4691 and 0.4780 and UEM of Poland, Finland, Czech Republic drop to level of 0.6. Consequently, this study has a policy inquiry regarding why such differences occur among these countries.

To discuss the policy inquiry, SEN and SEM measures are summarized in fourth and seventh column of Table 2. The SEN scores of France and Italy are 0.6523 and SENs of United States and Canada are close to 0.5. The SEM level of EU countries is above 0.8. However, the SEM is 0.4691 and 0.4863 for United States and Canada separately. The empirical results imply that EU countries pay more attention to balanced development in terms of economy and environment, especially in environment.

It is widely known that even though the economy of Europe was the largest and Europe was the richest region as measured by assets under management in 2008, Eurozone had gone into recession in the third quarter of 2008. In early 2010, fears of a sovereign debt crisis occurred in some countries in Europe, especially Greece, Ireland, Spain, and Portugal. Hence, we have inquiry regarding the current economic and environmental performance of European countries comparing to North America.

### International comparison

To obtain implications further, all countries are divided into two groups as continents. The first group is including all twenty-three EU countries and the second group incorporates two countries in North America.

This study examines the null hypotheses ($H_0$), summarized as follows:
$H_0$: There are no differences of unified efficiency scores between the two continents.

$H_a$: At least one of the unified efficiency scores between the two continents is different.

**Table 3 Unified efficiency mean and standard deviation of two groups**

<table>
<thead>
<tr>
<th>Country</th>
<th>UENv</th>
<th>UENc</th>
<th>SEN</th>
<th>UEMv</th>
<th>UEMc</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>0.8132 (0.2063)</td>
<td>0.7077 (0.2129)</td>
<td>0.8696 (0.1305)</td>
<td>0.9203 (0.1171)</td>
<td>0.8479 (0.1293)</td>
<td>0.9230 (0.0886)</td>
</tr>
<tr>
<td>North America</td>
<td>1.0000 (0.0000)</td>
<td>0.5124 (0.0384)</td>
<td>0.5124 (0.0384)</td>
<td>0.9915 (0.0121)</td>
<td>0.4736 (0.0063)</td>
<td>0.4777 (0.0122)</td>
</tr>
</tbody>
</table>

Note: Standard deviation is listed within ( )..

**Table 3 summarizes the means and standard deviations of all efficiency scores. North America outperforms EU in terms of economy and environment under variable RTS and DTS. However, after considering the size effect, the SEN and SEM drastically drop to half in North America. Consequently, EU outperforms North America in terms of economy and environment.**

**Table 4 The p-value of t-test of UEN, UEM and SEN, SEM**

<table>
<thead>
<tr>
<th></th>
<th>UENv</th>
<th>UENc</th>
<th>SEN</th>
<th>UEMv</th>
<th>UEMc</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU VS North America</td>
<td>0.2219</td>
<td>0.2162</td>
<td>0.0009</td>
<td>0.4080</td>
<td>0.0005</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Table 4 shows the p-values of the t-test results. The SEN and SEM are strongly significant at the 0.1% level. This indicates that EU significantly outperforms North America in both economic and environmental performance by considering the scale efficiency.

In order to meliorate the current energy crisis produced by Russia, the EU aims to increase the share of renewable energy of whole consumption and achieve energy savings. Through the attainment of these targets, the EU can combat the climate change and air pollution, decrease its dependence on foreign fossil fuels and keep energy affordable. There are many energy strategies proposed in EU. For example, making EU more energy efficient by accelerating investment into efficient buildings, eco-designed products and transport. Furthermore, the EU implements the strategic energy technology plan to accelerate the development such as solar power, smart grids and carbon capture and storage. On the other hand, after years of economic crisis, unemployment is stuck near its record high of 12% and the debt mountain continues to grow. Many EU countries suffer a sharp fall in living standards. People do not have confidence to their economic growths.

Under such current serious energy and economic crises, all people in EU are more sensitive to economic and energy saving so that they pay attention to energy usage and spending. For example, people prefer to small cars and electronic cars are most popular in Europe. Many products should meet Eco-design requirements for energy intense. Our empirical analysis indicates that EU countries pay more attention to environment even though they care both economy and environment. It can be confirmed by some EU strategies. For example, the EU countries try to reduce greenhouse gas emission by 20%. All EU countries promote new transport sector with at least 10% renewable energy.

Turning to North America, the United States (US) is the world’s largest national economy. The US has one of the world’s largest and most influential financial markets. Following the financial crisis of 2007-2008, the US economy began to recover in the second half of 2009 and as of Feb. 2015, unemployment had declined from 10% to 5.5%. Americans have the highest average household income among OECD nations. The US has abundant natural resources, a well-developed infrastructure and high productivity. The US is the world’s second largest...
producer and consumer of electricity and world’s third largest producer of oil and natural gas. Primary energy consumption in US was 18% of world total primary energy consumption in 2012. It is easy to imagine the polluted emission with such a high consumption level of energy. Comparing to European people, Americans usually do not worry about the energy usage. For example, the big trucks and SUVs are most popular models in US and can be observed everywhere. The lights are not shut down in commercial and residential buildings at nights, which make the cities and towns bright even though nobody uses the properties. Especially, the US focuses on economy recovery in current years. Therefore, US pay more attention on economy recovery and ignore the environmental protection.

Canada is one of the world’s wealthiest nations. Canada is unusual among developed countries in the importance of the primary sector, with the logging and oil industries being two of Canada’s most important. Canada closely resembles the US in its market-oriented economic system and pattern of production. On the other hand, Canada is one of the few developed nations that are net exporters of energy. The vast Athabasca oil sands give Canada the world’s third largest reserves of oil. Hydroelectric power is an inexpensive and relatively environmentally friendly source of abundant energy in British Columbia and Quebec. Partly because of this, Canada is also one of the world’s highest per capita consumers of energy. Because of America-Canada free trade agreement, the economies of US and Canada are combined together. Canada enjoys a substantial trade surplus with the US and Canada is the US’ largest foreign supplier of energy including oil, gas and electricity. Therefore, the economic and energy consumption of two countries shows the similar pattern. This proves that the US and Canada pay much more attention to economy, but ignore the protection of environment.

This may be explained by the government actions of North America and EU for recession. North America countries still advocate Keynesian theory, therefore, they continued fiscal sustained stimulus spending. On the other hand, EU countries leaders prefer to new classical economic theory which opposed stimulus entirely and they believe substantial austerity drives. Therefore, the immediate fiscal tightening behaviors were observed in some EU countries.

Comparison between two EU groups: The development difference is observed between EU and North America counties from the last section. Drafted in 1948 during the cold war, Eastern EU is communist region outside the Soviet Union and Western EU is a defensive alliance as opposed to Soviet influence among non-communist nations. In history, the Eastern EU countries were mostly behind the Western EU countries in economy progress. Then, the current development status inside the EU region and regional difference between Eastern EU and Western EU is our concern in next step. For the purpose, we further divide the EU countries into two regions - Eastern EU and Western EU. Table 5 summarizes the countries in two regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern EU</td>
<td>Austria, Czech Republic, Estonia, Hungary, Poland, Slovak Republic, Slovenia</td>
</tr>
<tr>
<td>Western EU</td>
<td>Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom</td>
</tr>
</tbody>
</table>

Then this study examines the null hypotheses ($H_0$), summarized as follows:

$H_0$: There are no differences of unified efficiency scores among the two EU regions.

$H_a$: At least one of the unified efficiency scores among the two regions is different.
In order to identify the regional difference, especially the difference between Eastern EU and Western EU, Table 6 summarizes the mean and standard deviation of all efficiency scores for two regions. The results indicate that Western EU outperforms Eastern EU in both economy and environment. For example, the UENV of Western EU is higher about 0.13, SEN is higher about 0.10 and UEMV and SEM are higher about 0.07. Especially the unified efficiency scores under constant RTS and DTS of Western EU are higher than Eastern EU. For example, UENC is higher about 0.20 and UEMc is higher over 0.12. Since UENC excludes the influence of undesirable outputs, the Western EU performs even much better in GDP and electricity generation.

<table>
<thead>
<tr>
<th>Country</th>
<th>UENV</th>
<th>UENC</th>
<th>SEN</th>
<th>UEMV</th>
<th>UEMc</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern EU</td>
<td>0.7216 (0.2234)</td>
<td>0.5736 (0.1663)</td>
<td>0.8010 (0.1193)</td>
<td>0.8708 (0.1273)</td>
<td>0.7622 (0.1292)</td>
<td>0.8797 (0.1133)</td>
</tr>
<tr>
<td>Western EU</td>
<td>0.8533 (0.1920)</td>
<td>0.7663 (0.2083)</td>
<td>0.8997 (0.1270)</td>
<td>0.9419 (0.1095)</td>
<td>0.8854 (0.1137)</td>
<td>0.9419 (0.0718)</td>
</tr>
</tbody>
</table>

Note: Standard deviation is listed within ( ).

Table 7 summarizes the t-test results of all unified efficiency measurements and scale measurement for the two regions. As expected from the previous findings, the countries in Western EU are highly significantly different at 5% level in economy and environmental protection without undesirable output influence. The better scale management on economic development in Western EU is only significant at 10% level. However, the performance difference in terms of both economy and environment, considering both desirable and undesirable outputs between Western EU and Eastern EU, is not significant as well as the scale management on environmental protection considering the size effect. Hence, the performance difference is only observed in economy between Western EU and Eastern EU. Considering the size effect, the economic difference is decreased, which implies the improved economy of Eastern EU currently.

<table>
<thead>
<tr>
<th>Country</th>
<th>UENV</th>
<th>UENC</th>
<th>SEN</th>
<th>UEMV</th>
<th>UEMc</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern VS Western</td>
<td>0.1639</td>
<td>0.0428</td>
<td>0.0957</td>
<td>0.1862</td>
<td>0.0320</td>
<td>0.1244</td>
</tr>
</tbody>
</table>

Due to the significant performance difference in economy between Eastern EU and Western EU, we have inquiry that whether the difference between EU and North America comes from Western EU. Table 8 summarizes the t-test results of efficiency measurements for Eastern EU and North America. Comparing to Table 4, which tests the performance difference between EU and North America, the values in Table 8 are similar and increase. This proves the performance difference between EU and North America in both economy and environmental protection. Even though the significance is decreased between Eastern EU and North America, the Eastern EU still defeats North America in terms of economic and environmental performance.

<table>
<thead>
<tr>
<th>Country</th>
<th>UENV</th>
<th>UENC</th>
<th>SEN</th>
<th>UEMV</th>
<th>UEMc</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern VS Western</td>
<td>0.1371</td>
<td>0.6361</td>
<td>0.0144</td>
<td>0.2426</td>
<td>0.0197</td>
<td>0.0020</td>
</tr>
</tbody>
</table>
Therefore, all EU countries outperform the North America countries, especially in terms of environmental protection. The “imbalanced development” in economy and environment may occur in North America nowadays.

POLICY IMPLICATION

The countries in North America, including Canada and the United States, have focused on economic recovery since financial crisis in 2007-2008 and the environment protection is neglected. For example, US regulation was authorized to curb planet-warming carbon pollution from coal-fired power plants, which would ultimately shut down hundreds of coal plants. The move of some corporations that tried to meet the requirements of the act wreaks economic havoc. Therefore, the 14 states and the coal companies contend that the environmental agency lacks the authority to issue the regulation and petitioned the court to block it from finalizing the proposed rule. This indicates the implementation challenge of environment protection of the US and at the same time, it proves the fact that the economy is the first concern of the United States.

The empirical results of this study imply three implications: First, the US and the Canadian governments should reinforce their regulations and rules of environmental protection to industries. The environment protection agency should be given stronger power to monitor the corporations and realize the target of environmental protection. Second, much of the energy is wasted through transmission, heat loss and inefficient technology, which lead to increased carbon pollution. The governments should invest on increasing energy efficiency to combat climate change and air pollution. Finally, people’s living habit and attitude is another crucial important factor for protecting environment and saving energy. The idea and acknowledge of energy saving and environmental protection should be emphasized and promoted in North America in every family and corporation. The governments should consider adding environmental education.

CONCLUSION

This study applied DEA environmental assessment, proposed by Sueyoshi, Goto (2012a, 2012b, 2012c, 2012d, 2012e, 2012f) and other researchers (e.g., Sueyoshi and Yuan, 2015), to examine differences in the level of social sustainability (economic success and environmental protection) between European Union and North America countries. It focuses on current energy usage and economic recovery of two most developed continents. The methodology incorporates the scale efficiency measurement under the concept of natural and managerial disposability. Finally, the t-test is applied to DEA results to statistically examine whether there is performance difference in terms of economy and environment for both continents and inside EU.

The empirical results of this study have rejected the hypothesis, implying the performance difference in both economy and environment. Especially, environment is paid more attention in EU countries. In order to maintain development sustainability and quickly realize the target of economy recovery, the US and Canada should pay more attention to energy usage and environmental protection even though they have abundant energy resources. The energy is so limited that North America should not duplicate the energy crisis of EU countries. Simultaneously, more strict regulations and integrated policy should be reinforced in many different industries and finalize the strategic plans such as the President’s Climate Action Plan in the United States. In order to perform strategic goals, North America countries should
continue to promote scientific and technological innovations and sponsor basic research in different fields of sciences.

In conclusion, it is hoped that this study makes a contribution on DEA environmental assessment.

REFERENCES


Sueyoshi, T., Goto, M., 2013. Returns to scale vs. damages to scale in data envelopment analysis: An impact of U.S. clean air act on coal-fired power plants. Omega 41, 164-175.