China' Sustainability on Economy and Energy using DEA Assessment

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The IAFOR International Conference on Sustainability, Energy & the Environment – Hawaii 2017
Official Conference Proceedings

Abstract
From the "13th five year" plan, China now is directing to transit to the green economy for not only relying on GDP performance, but also ensuring the environmental protection. It is crucial to have the energy plan, which can build up safe, efficient and sustainable energy strategy systems. This study discusses the concept of Undesirable Congestion (UC) under natural disposability and Desirable Congestion (DC) under managerial disposability and links them with Returns to Damage (RTD) and Damages to Return (DTR). RTD and DTR are newly derived from a conventional concept of Returns to Scale (RTS). This study compares between RTD under UC and DTR under DC and applies the proposed methodology to 30 Chinese provinces on their economic and energy planning for sustainable development. Three important findings are identified: First, the Chinese government has historically paid attention to the economic development, but ignoring environmental protection. Second, there was an increasing trend in improving the economy and environment. Finally, China focused on large provinces especially municipalities in terms of energy policy concerns. Thus, Chinese government should consider the privatization from public to private energy firms. It can not only improve the energy management and monitoring by government, but also increase the economic efficiency in market so that GDP can be increased. In further, the increased economic growth can better the economic imbalance of China.

Keywords: Energy, Congestion, Industrial Policy

Introduction

China is the most rapidly developed country in past 10 years in terms of economy. At the same time, the air pollution problem became a major concern for its neighbor countries. The rapid economic development comes along with the air pollution in history. For example, the United of Kingdom in last century. The great smog events caused 12,000 fatalities according to most recent report. Later the relationship of air quality and health led to several changes in practices and regulations. It costs so many years' governance to improve the air quality.

In order to avoid the irreversible outcome from rapid economic development and duplication of UK's development mistake, China should seek social sustainability on economy and environment before the air quality goes worse. And the energy planning plays an important role in controlling air pollutions.

In this study, the social sustainability, based upon our empirical measurability by mathematical programming, implies "a synchronized development of both (a) economic prosperity for reducing the level of poverty and enhancing the standard of living and (b) environmental protection for reducing the level of pollution". The components of such social sustainability are discussed within the conceptual framework of natural disposability and managerial disposability, respectively, where the concept of disposability implies inefficiency elimination. Note that the natural disposability has a priority order where the first priority is operational (economic) performance and the second priority is environmental performance. An opposite priority is found in managerial disposability. Thus, the concept of social suitability will be discussed and measured within our analytical capability. Therefore, this study does not consider qualitative aspects (e.g., culture, law, politics and philosophy) regarding the social sustainability.

DEA environmental assessment can be used to overcome the difficulty on global warming and climate change by combining the technology development with managerial challenges. As an extension of previous studies, this study applies the concept of Undesirable Congestion (UC) and Desirable Congestion (DC) along with its linkage with Returns to Damage (RTD) and Damages to Return (DTR). It is easily imagined that no study has explored RTD under UC and DTR under DC in not only DEA environmental assessment but also production economics. Also in order to overcome the DEA efficiency difficulty, this study equips DEA with an analytical capability for multiplier restriction to improve the measurement reliability on RTD under UC and DTR under DC.

The methodology has been applied to energy planning in China. The economic imbalance and serious environmental pollution are found. In order to control air pollutions and better development, Chinese government should promote the privatization in near future as the policy implication.

Literature Review

The development of DEA was due to the contributions of Professor W.W. Cooper. See Glover and Sueyoshi (2009) and Ijiri and Sueyoshi (2010) on his contributions of

Professor Cooper in DEA development. An important feature of the previous DEA studies is that they have developed methodological frameworks of DEA, but lacking a conceptual framework for its environmental assessment. The first article, which has discussed the conceptual framework such as natural and managerial disposability, can be found in Sueyoshi and Goto (2012).

An occurrence of congestion has been widely examined in many previous studies (e.g., Cooper et al, 2001, Sueyoshi and Sekitani, 2008) within a conventional framework of DEA. It is impossible for this study to apply their approaches to discuss the occurrence for environmental assessment because their approaches did not consider the output separation to desirable and undesirable categories. Furthermore, their approaches did not separate the occurrence into UC and DC.

Most of Chinese energy firms have been operating under public ownership. Sueyoshi and Goto (2012) that has documented the ownership portion of three Chinese petroleum companies. Public agencies on environmental protection usually have a difficulty in monitoring and controlling public companies because their governances are connected to each other. To terminate such a political linkage, the privatization of public firms, in particular energy firms, is necessary for Chinese future. See a series of studies (e.g., Sueyoshi, 1991, 1997, 1998, 1999; Sueyoshi et al., 2010) on privatization whose performance changes have been measured by DEA.

Methodology and methods

This study considers that there are n DMUs (Decision Making Units: corresponding to an organization to be evaluated). The j-th DMU ($j = 1, .., n$) uses a column vector of inputs (X_j) in order to yield not only a column vector of desirable outputs (G_j) but also a column vector of undesirable outputs (B_j), where $X_j = (x_{1j}, x_{2j}, .., x_{mj})^T$, $G_j = (g_{1j}, g_{2j}, .., g_{sj})^T$ and $B_j = (b_{1j}, b_{2j}, .., b_{hj})^T$. Here, the superscript "T" indicates a vector transpose. These column vectors are referred to as "production factors" in this study. It is assumed that $X_j > 0$, $G_j > 0$ and $B_j > 0$ for all $j = 1, .. , n$, where all components of the three vectors are strictly positive.

The data ranges for adjustment are determined by the upper and lower bounds on inputs and those of desirable and undesirable outputs. These upper and lower bounds are specified by

$$R_i^x = (m+s+h)^{-1}\left(max\left\{x_{ij} \,\middle|\, j = 1,\cdots,n\right\} - min\left\{x_{ij} \,\middle|\, j = 1,\cdots,n\right\}\right)^{-1}$$

$$R_r^g = (m+s+h)^{-1}\left(max\left\{g_{rj} \,\middle|\, j = 1,\cdots,n\right\} - min\left\{g_{rj} \,\middle|\, j = 1,\cdots,n\right\}\right)^{-1} \text{ and}$$

$$R_f^b = (m+s+h)^{-1}\left(max\left\{b_{fj} \,\middle|\, j = 1,\cdots,n\right\} - min\left\{b_{fj} \,\middle|\, j = 1,\cdots,n\right\}\right)^{-1}.$$

To examine the occurrence of UC under natural disposability, this study proposes the following model that maintains equality constraints (so, no slack variable) on undesirable outputs:

$$
\begin{aligned}
&Maximize \quad \xi + \varepsilon_s [\sum_{i=1}^{m} R_i^{x-} d_i^{x-} + \sum_{r=1}^{s} R_r^g d_r^g] \\
&s.t. \quad \sum_{j=1}^{n} x_{ij} \lambda_j + d_i^{x-} = x_{ik} \quad (i = 1, .., m), \\
&\sum_{j=1}^{n} g_{rj} \lambda_j - d_r^g - \xi g_{rk} = g_{rk} \quad (r = 1, .., s), \\
&\sum_{j=1}^{n} b_{fj} \lambda_j + \xi b_{fk} = b_{fk} \quad (f = 1, .., h), \\
&\sum_{j=1}^{n} \lambda_j = 1, \\
&\lambda_j \geq 0 \ (j = 1, .., n), \ \xi : URS \\
&d_i^{x-} \geq 0 \ (i = 1,..,m) \ \& \ d_r^g \geq 0 \ (r = 1,..,s).
\end{aligned} \tag{1}
$$

Model (1) drops slack variables related to undesirable outputs (B) so that they are considered as equality constraints. The other constraints regarding inputs and desirable outputs are considered as inequality because they have slack variables in Model (1). Model (1) has the following dual formulation:

$$
\begin{aligned}
&Minimize \quad \sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
&s.t. \quad \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq 0 \quad (j = 1, ..,n), \\
&\sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} = 1, \\
&v_i \geq \varepsilon_s R_i^x \quad (i = 1, .., m), \\
&u_r \geq \varepsilon_s R_r^g \quad (r = 1, .., s), \\
&w_f : URS \quad (f = 1, .., h) \ \& \\
&\sigma : URS.
\end{aligned} \tag{2}
$$

An important feature of Model (2) is that the dual variables ($w_f : URS$ for $f = 1, .., h$) are unrestricted in their signs because the constraints on undesirable outputs are expressed by equality (no slack) in Model (1). The dual variables are often referred to as "multipliers" in the DEA community.

A unified efficiency score of the k-th DMU under natural disposability becomes

$$
UEN(UC) = 1 - [\xi^* + \varepsilon_s (\sum_{i=1}^{m} R_i^x d_i^{x-*} + \sum_{r=1}^{s} R_r^g d_r^{g*})] = 1 - [\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^*], \tag{3}
$$

which incorporates a possible occurrence of UC. All variables used in Equation (3) are determined on the optimality of Models (1) and (2). The equation within the parenthesis, obtained from the optimality of Models (1) and (2), indicates the level of unified inefficiency under natural disposability. The unified efficiency in the case, or $UEN(UC)$, is obtained by subtracting the level of inefficiency from unity.

An important advantage of Model (1) is that it can incorporate prior information as side constraints for multiplier restrictions. For example, DEA environmental assessment usually divides an observation on each production factor by the average in order to avoid a case where a data set with a large magnitude dominates the other data sets with a small magnitude in DEA computation. Therefore, such a data manipulation is important for DEA to enhance the computational reliability. As a result, all the observations used in this study are unit-less, so indicating the importance of each production factor. Along with the data adjustment, it is possible for us to incorporate addition side conditions on production factors by the following manner:

$$\text{Inputs: } -1 \le v_{i'}/v_i \le 1 \; (i' > i = 1, ..,m). \tag{4}$$

$$\text{Desirable outputs: } -1 \le u_{r'}/u_r \le 1 \; (r' > r = 1, ..,s). \tag{5}$$

$$\text{Undesirable outputs: } -1 \le w_{f'}/w_f \le 1 \; (f' > f = 1, ..,h). \tag{6}$$

Model (2), equipped with Equations (4)-(6), becomes as follows:

$$\begin{aligned}
&\text{Minimize} && \sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
&\text{s.t.} && \sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \ge 0 && (j = 1, ..,n), \\
& && \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} = 1, \\
& && v_i \ge \varepsilon_s R_i^x && (i = 1, .., m), \qquad (7) \\
& && u_r \ge \varepsilon_s R_r^g && (r = 1, .., s), \\
& && w_f : URS && (f = 1, .., h), \\
& && \sigma : URS, \\
& && -1 \le v_{i'}/v_i \le 1 && (i' > i = 1, ..,m), \\
& && -1 \le u_{r'}/u_r \le 1 && (r' > r = 1, ..,s) \;\& \\
& && -1 \le w_{f'}/w_f \le 1 && (f' > f = 1, ..,h).
\end{aligned}$$

The level of *UEN(UC)* is determined by

$$UEN(UC) = 1 - [\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^*],$$

(8)

where all the dual variables are identified on the optimality of Model (7). Equation (8) is different from Equation (3) because the side constrains (4)-(6) are additionally incorporated into Model (7). Here, it is important to note that Equation (8) is different from Equation (3) because the former incorporates the proposed multiplier restriction, or Equations (4)-(6), while the latter does not have such additional constraints. Therefore, the two models produce different *UEN(UC)* measures.

After computing Model (7), a possible occurrence of UC is determined by the following rule along with the assumption that Model (7) produces a unique optimal solution (i.e. unique projection and a unique reference set):

(a) if $w_f^* < 0$ for some (at least one) f, then "strong UC" occurs on the k-th DMU,
(b) if $w_f^* > 0$ for all f, then "no UC" occurs on the k-th DMU, and
(c) In the others, including $w_f^* = 0$ for some (at least one) f, then "weak UC" occurs on the k-th DMU.

It is important to note that if $w_f^* < 0$ for some *f* and $w_{f'}^* = 0$ for the other *f'*, then both strong UC and weak UC may coexist on the k-th DMU. In that case, this study considers it as an occurrence of the strong UC on the DMU.

RTD Measurement under a Possible Occurrence of Undesirable Congestion (UC)

Let the dual variables of the k-th DMU, obtained from Model (7), be v_i^* ($i = 1, 2, .., m$), u_r^* ($r = 1, 2, .., s$), w_f^* ($f = 1, 2, .., h$) and σ^* on the optimality. Then, the estimated supporting hyperplane on the k-th DMU is expressed by

$$\sum_{r=1}^{s} u_r^* g_r = \sum_{i=1}^{m} v_i^* x_i + \sum_{f=1}^{h} w_f^* b_f + \sigma^* , \tag{9}$$

which is characterized by $\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma,\ j \in R_k$, where R_k is a reference set for the k-th DMU, and $\sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} = 1$.

The degree (Dg) of RTD, or DgRTD, under a possible occurrence of UC, on the k-th DMU by

$$\begin{aligned} DgRTD(UC) &= \Big(\sum_{f=1}^{h} w_f^* b_f\Big) / \Big(\sum_{r=1}^{s} u_r^* g_r\Big) \\ &= \Big(\sum_{f=1}^{h} w_f^* b_f\Big) / \Big(\sum_{i=1}^{m} v_i^* x_i + \sum_{f=1}^{h} w_f^* b_f + \sigma^*\Big) \\ &= 1/\Big[1 + \Big(\sigma^* + \sum_{i=1}^{m} v_i^* x_i\Big) / \Big(\sum_{f=1}^{h} w_f^* b_f\Big)\Big] \end{aligned} \tag{10}$$

As mentioned previously, this study assumes that Model (7) has both a unique projection of an inefficient DMU onto an efficiency frontier and a unique reference set for the DMU.

The type of RTD is classified by the following rule on the k-th DMU:

(a) Increasing RTD $\Leftrightarrow$ There exists an optimal solution of Model (7) that satisfies all $w_f^* > 0$ ($f = 1, .., h$) and $\sigma^* + \sum_{i=1}^{m} v_i^* x_i < 0$,

(b) Constant RTD $\Leftrightarrow$ There exists an optimal solution of Model (7) that satisfies all $w_f^* > 0$ ($f = 1, .., h$) and $\sigma^* + \sum_{i=1}^{m} v_i^* x_i = 0$,

(c) Decreasing RTD $\Leftrightarrow$ Any optimal solution of Model (7) that satisfies all $w_f^* > 0$ ($f = 1, .., h$) and $\sigma^* + \sum_{i=1}^{m} v_i^* x_i > 0$,

(d) Negative RTD $\Leftrightarrow$ any optimal solution of Model (7) that satisfies $w_f^* < 0$ for at least one $i \in \{1, K, m\}$, and

(e) No RTD $\Leftrightarrow$ All other cases excluding (a) to (d).

Difference between UC and RTD: The type of UC is identified by the sign of dual variables (w_f^*). The type of UC is classified into the three categories. Meanwhile, these measures related to RTD are determined by not only the sign of dual variables (w_f^*) but also the sign of $\sum_{i=1}^{m} v_i^* x_i + \sigma^*$. The type of RTD is classified into the five categories. Figure 7 visually classifies the type of RTD under a possible occurrence of UC.

At the end of this section, it is necessary to summarize three concerns related to Model (7) and Equation (10) as well as the proposed RTD classification. First, Model (7) assumes a unique solution, so implying no occurrence on multiple projections and multiple reference sets. Second, Equation (10) is effective on only efficient DMUs, not inefficient ones. In the case of inefficiency, Equation (10) needs to incorporate a projection onto an efficiency frontier by eliminating slacks from the observed production factors. Finally, the type of RTD is determined by measuring the upper and lower bound of $\sum_{i=1}^{m} v_i^* x_i + \sigma^*$. The proposed approach is just an approximation method for the RTD measurement for our descriptive convenience. Figure 1 visually classifies an occurrence of UC and RTD classification (source: Sueyoshi and Yuan (2016)).

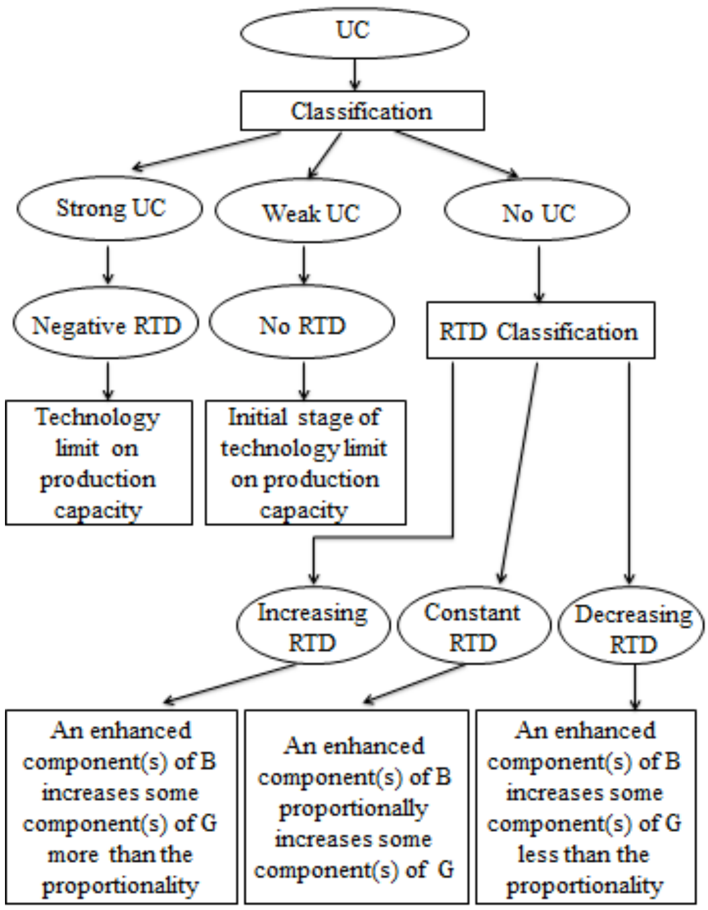

Figure 1: RTD under UC

Source: Sueyoshi & Yuan (2016).

A Possible Occurrence of Desirable Congestion

This study can identify an occurrence of Desirable Congestion (DC) under managerial disposability. To examine the occurrence, this study proposes the following model that maintains equality constraints (so, no slack variable) on desirable outputs:

$$\begin{aligned}
& Maximize \quad \xi + \varepsilon_s \Big[\sum_{i=1}^{m} R_i^x d_i^{x+} + \sum_{f=1}^{h} R_f^b d_f^b \Big] \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}\lambda_j - d_i^{x+} = x_{ik} \quad (i = 1,..,m), \\
& \qquad \sum_{j=1}^{n} g_{rj}\lambda_j - \xi g_{rk} = g_{rk} \quad (r = 1,..,s) \\
& \qquad \sum_{j=1}^{n} b_{fj}\lambda_j + d_f^b + \xi b_{fk} = b_{fk} \quad (f = 1,..,h), \\
& \qquad \sum_{j=1}^{n} \lambda_j = 1, \\
& \qquad \lambda_j \geq 0 \ (j = 1,..,n),\ \xi : URS,\ d_i^{x+} \geq 0 \ (i = 1,..,m), \\
& \qquad and \ \ d_f^b \geq 0 \ (f = 1,..,h).
\end{aligned} \qquad (11)$$

Model (11) drops slack variables related to desirable outputs so that they are considered as equality constraints. The other groups of constraints on inputs and undesirable outputs maintain slacks so that they can be considered as inequality constraints. For example, $\sum_{j=1}^{n} x_{ij}\lambda_j - d_i^{x+} = x_{ik}$ is equivalent to $\sum_{j=1}^{n} x_{ij}\lambda_j \geq x_{ik}$ for all i. The description on input slacks is also applicable to undesirable outputs. Model (11) has the following dual formulation:

$$
\begin{aligned}
\text{Minimize} \quad & -\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
\text{s.t.} \quad & -\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \geq 0 \quad (j = 1, .., n), \\
& \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} = 1, \\
& v_i \geq \varepsilon_s R_i^x \quad (i = 1, .., m), \\
& u_r : URS \quad (r = 1, .., s), \\
& w_f \geq \varepsilon_s R_f^d \quad (f = 1, .., h)\ \& \\
& \sigma : URS.
\end{aligned}
\tag{12}
$$

An important feature of Model (11) is that the dual variables (u_r: URS for $r = 1, .., s$) are unrestricted in their signs because Model (11) drops slack variables related to desirable outputs.

A unified efficiency score, or $UEM(DC)$ of the k-th DMU, with a possible occurrence of DC, under managerial disposability is determined by:

$$
UEM(DC) = 1 - [\xi^* + \varepsilon_s [\sum_{i=1}^{m} R_i^x d_i^{x+*} + \sum_{f=1}^{h} R_f^b d_f^{b*}]] = 1 - [-\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^*], \tag{13}
$$

where all variables are determined on the optimality of Models (11) and (12). The equation within the parenthesis, obtained from the optimality of Models (11) and (12), indicates the level of unified inefficiency under managerial disposability. The unified efficiency is obtained by subtracting the level of inefficiency from unity.
As discussed on Model (7), Model (6) can incorporate prior information as follows:

$$
\begin{aligned}
&\text{Minimize} \quad -\sum_{i=1}^{m} v_i x_{ik} - \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} + \sigma \\
&\text{s.t.} \quad -\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma \ \geq \ 0 \quad (j = 1, ..,n), \\
&\qquad \sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} \ = \ 1, \\
&\qquad v_i \geq \varepsilon_s R_i^x \quad (i = 1, .., m), \\
&\qquad u_r: URS \quad (r = 1, .., s), \\
&\qquad w_f \geq \varepsilon_s R_f^b \quad (f = 1, .., h), \\
&\qquad \sigma: URS, \\
&\qquad -1 \leq v_{i'}/v_i \leq 1 \quad (i' > i = 1, ..,m), \\
&\qquad -1 \leq u_{r'}/u_r \leq 1 \quad (r' > r = 1, ..,s) \ \& \\
&\qquad -1 \leq w_{f'}/w_f \leq 1 \quad (f' > f = 1, ..,h).
\end{aligned}
$$

(14)

The level of *UEM(DC)* is determined by

$$
UEM(DC) = 1 - [-\sum_{i=1}^{m} v_i^* x_{ik} - \sum_{r=1}^{s} u_r^* g_{rk} + \sum_{f=1}^{h} w_f^* b_{fk} + \sigma^*],
$$

(15)

where all the dual variables are identified on the optimality of Model (14). Equation (15) is different from Equation (13) because Model (15) incorporates the additional side constrains (4)-(6). Thus, Equations (15) and (13) produce different *UEM(DC)* measures.

After solving Model (14), this study can identify a possible occurrence of DC, or eco-technology innovation, by the following rule under the assumption on a unique optimal solution (i. e. unique projection and a unique reference set):

(a) if $u_r^* < 0$ for some (at least one) r, then "strong DC" occurs on the k-th DMU,

(b) if $u_r^* > 0$ for all r, then "no DC" occurs on the k-th DMU and

(c) In the others, including $u_r^* = 0$ for some (at least one) f, then "weak DC" occurs on the k-th DMU.

Note that if $u_r^* < 0$ for some *r* and $u_{r'}^* = 0$ for the other *r'*, then the weak and strong DCs coexist on the k-th DMU. This study considers it as the strong DC, so indicating technology innovation on undesirable outputs. It is important to note that $u_r^* < 0$ for all r is the best case because an increase in any desirable output always decreases an amount of undesirable outputs. Meanwhile, if $u_r^* < 0$ is identified for some r, then it indicates that there is a chance to reduce an amount of undesirable output(s). Therefore, this study considers the second case as an occurrence of DC.

DTR under Desirable Congestion (DC)

Let the dual variables of the k-th DMU, obtained from Model (14), be v_i^* (i = 1, 2, .., m), u_r^* (r = 1, 2, .., s), w_f^* (f = 1, 2, .., h) and σ^*. Then, an estimated supporting hyperplane on the k-th DMU is specified by

$$\sum_{f=1}^{h} w_f^* b_f = \sum_{r=1}^{s} u_r^* g_r + \sum_{i=1}^{m} v_i^* x_i - \sigma^* . \tag{16}$$

The equation is characterized by $-\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r g_{rj} + \sum_{f=1}^{h} w_f b_{fj} + \sigma,\ j \in R_k$, where R_k is a reference set of the k-th DMU, and $\sum_{r=1}^{s} u_r g_{rk} + \sum_{f=1}^{h} w_f b_{fk} = 1$.

This study assumes that Model (14) has both a unique projection of an inefficient DMU onto an efficiency frontier and a unique reference set for the projected DMU. Then, the degree (Dg) of the DTR, or DgDTR, is measured by

$$\begin{aligned} DgDTR &= \Big(\sum_{r=1}^{s} u_r^* g_r\Big) / \Big(\sum_{f=1}^{h} w_f^* b_f\Big) \\ &= \Big(\sum_{r=1}^{s} u_r^* g_r\Big) / \Big(\sum_{i=1}^{m} v_i^* x_i + \sum_{r=1}^{s} u_r^* g_r - \sigma^*\Big) \\ &= 1/\Big[1 - \Big(\sigma^* - \sum_{i=1}^{m} v_i^* x_i\Big) / \Big(\sum_{r=1}^{s} u_r^* g_r\Big)\Big] \end{aligned} \tag{17}$$

Consequently, the type of DTR is classified by the following rule on the k-th DMU:

(a) Increasing DTR $\Leftrightarrow$ There is an optimal solution of Model (14) that satisfies all $u_r^* > 0$ $(r = 1, .., s)$ and $\sigma^* - \sum_{i=1}^{m} v_i^* x_i > 0$,

(b) Constant DTR $\Leftrightarrow$ There exists an optimal solution of Model (14) that satisfies all $u_r^* > 0$ $(r = 1, .., s)$ and $\sigma^* - \sum_{i=1}^{m} v_i^* x_i = 0$,

(c) Decreasing DTR $\Leftrightarrow$ There is an optimal solution of Model (14) that satisfies all $u_r^* > 0$ $(r = 1, .., s)$ and $\sigma^* - \sum_{i=1}^{m} v_i^* x_i < 0$,

(d) Negative DTR $\Leftrightarrow$ There is an optimal solution of Model (14) that satisfies $u_r^* < 0$ for at least one $r \in \{1, \ldots, s\}$, and

(e) No DTR $\Leftrightarrow$ All other cases excluding (a) to (d).

All the concerns discussed for the measurement of RTD are applicable to DTR. However, it is important to add that the type of DTR is determined by measuring the upper and lower bound of $\sigma^* - \sum_{i=1}^{m} v_i^* x_i$. The proposed approach is just an approximation method for the DTR measurement.

Difference between DC and DTR: The occurrence and type of DC are identified by the sign of dual variables (u_r^*). The type of DC is classified into three categories. Meanwhile, these measures related to DTR are determined by not only the sign of dual variables (u_r^*) but also the sign of $\sigma^* - \sum_{i=1}^{m} v_i^* x_i$. The type of DTR is classified into five categories. Figure 2 visually classifies an occurrence of DC and DTR classification (source: Sueyoshi and Yuan (2016)).

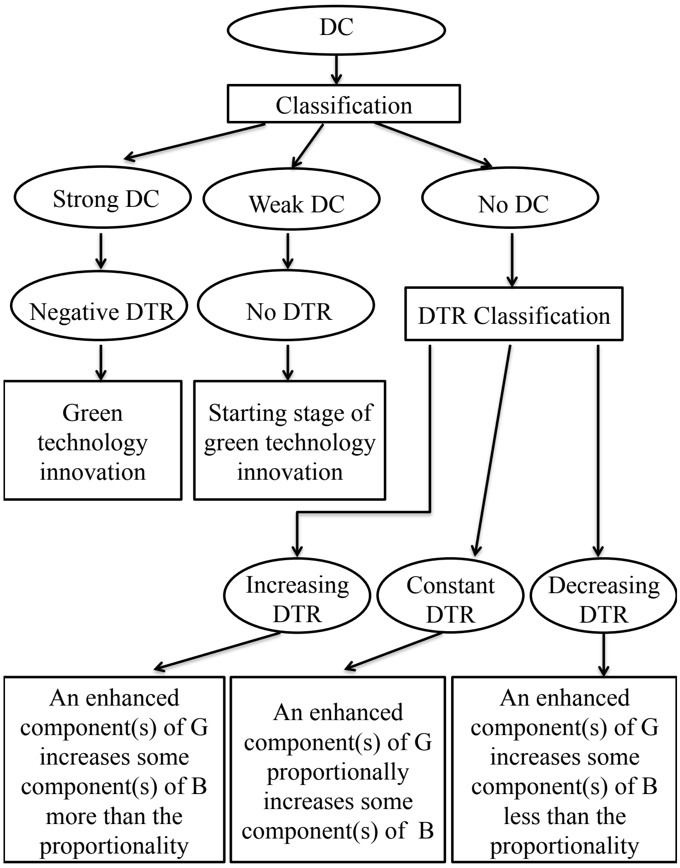

Figure 2: DTR under DC

(a) Source: Sueyoshi & Yuan (2016).

Table 1: UEN of 30 provinces in 2005-2012

Province	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	0.7740	0.8195	0.7357	0.7897	0.7873	0.9096	1.0000	1.0000	0.8520
Tianjin	0.5571	0.4960	0.5445	0.5750	0.5010	0.6266	0.7702	0.7866	0.6071
Hebei	0.5017	0.5389	0.6147	0.6837	0.7173	0.7415	0.7850	0.8164	0.6749
Shanxi	0.2961	0.2871	0.3177	0.4214	0.3761	0.4642	0.5132	0.5457	0.4027
Inner Mongolia	0.3789	0.3720	0.4673	0.5851	0.5702	0.6448	0.6219	0.5480	0.5235
Liaoning	0.4242	0.4235	0.4716	0.5135	0.5442	0.5978	0.6774	0.6928	0.5431
Jilin	0.5274	0.5044	0.5227	0.5441	0.5974	0.5804	0.6782	0.7162	0.5839
Heilongjiang	0.4123	0.4260	0.4330	0.4720	0.4760	0.5092	0.6127	0.6910	0.5040
Shanghai	0.6876	0.7400	0.7431	0.8518	0.7897	0.9096	1.0000	1.0000	0.8402
Jiangsu	0.7211	0.7515	1.0000	0.9409	0.9433	1.0000	1.0000	1.0000	0.9196
Zhejiang	0.6282	0.6625	0.7262	0.8731	0.9029	0.9969	0.9917	1.0000	0.8477
Anhui	0.7940	0.6694	0.6753	0.6955	0.7565	0.8102	0.9057	0.9422	0.7811
Fujian	1.0000	1.0000	1.0000	0.9214	1.0000	0.8846	0.9379	1.0000	0.9680
Jiangxi	1.0000	0.9522	1.0000	1.0000	0.9692	0.9484	0.9625	1.0000	0.9790
Shandong	0.6265	0.7537	0.7749	0.8577	0.8776	0.9126	0.9602	1.0000	0.8454
Henan	0.6101	0.5930	0.6589	0.7728	0.7662	0.8296	0.8880	0.9353	0.7567
Hubei	0.4922	0.4724	0.5280	0.6600	0.6557	0.7380	0.8808	1.0000	0.6784
Hunan	0.6575	0.7200	0.7992	0.8445	0.8841	0.9264	0.9788	1.0000	0.8513
Guangdong	0.6505	0.7503	0.8674	0.8986	0.8706	0.9745	1.0000	1.0000	0.8765
Guangxi	0.9603	0.8102	0.8511	1.0000	1.0000	0.9733	1.0000	1.0000	0.9494
Hainan	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9939	1.0000	0.9992
Chongqing	0.3696	0.3540	0.3944	0.4358	0.4468	0.4810	0.5751	0.5860	0.4553
Sichuan	0.4983	0.4752	0.5922	0.6274	0.5865	0.6618	0.7331	0.7452	0.6150
Guizhou	0.4980	0.4531	0.4493	0.4860	0.5329	0.5378	0.5091	0.6297	0.5120
Yunnan	0.5112	0.4611	0.5655	0.6535	0.6508	0.6243	0.7422	0.7637	0.6215
Shaanxi	0.3570	0.3080	0.3213	0.3693	0.3786	0.4102	0.4745	0.5029	0.3902
Gansu	0.3826	0.3080	0.3551	0.3331	0.2897	0.2902	0.3550	0.3756	0.3362
Qinghai	1.0000	0.3536	0.4523	0.3618	0.2963	0.3445	0.3598	0.3849	0.4441
Ningxia	1.0000	0.7704	0.4602	0.4696	0.4156	0.3903	0.3800	0.3544	0.5301
Xinjiang	0.3110	0.2384	0.2743	0.2644	0.2779	0.3168	0.3299	0.3225	0.2919
Average	0.6209	0.5822	0.6199	0.6634	0.6620	0.7012	0.7539	0.7780	0.6727

(a) UEN scores of thirty provinces during eight years from 2005 to 2012 use a pooled data set (240 = 30 x 8 observations).
(b) The increasing UEN from 2005 to 2012 indicated the improving performance in terms of economy.
(c) Source: Sueyoshi & Yuan (2016).

Table 2: UEM of 30 provinces in 2005-2012

Province	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	0.2860	0.2814	0.3158	0.4127	0.4209	0.4369	0.4853	0.5205	0.3950
Tianjin	0.3500	0.3362	0.4245	0.5002	0.4762	0.4687	0.4923	0.4557	0.4380
Hebei	0.5039	0.5531	0.6542	0.7209	0.7420	0.7530	0.8175	0.8328	0.6972
Shanxi	0.4873	0.4855	0.5463	0.6631	0.6472	0.7991	0.9162	1.0000	0.6931
Inner Mongolia	0.5109	0.5053	0.6483	0.8569	0.8708	1.0000	1.0000	0.9794	0.7965
Liaoning	0.4488	0.4452	0.5201	0.5345	0.5846	0.6885	0.7134	0.7396	0.5843
Jilin	0.4695	0.4808	0.5025	0.5607	0.5542	0.6066	0.6342	0.6573	0.5582
Heilongjiang	0.4154	0.4646	0.4629	0.5011	0.5112	0.5767	0.6254	0.7013	0.5323
Shanghai	0.4901	0.5106	0.5205	0.5452	0.5852	0.6030	0.6181	0.6928	0.5707
Jiangsu	0.5467	0.5622	0.6149	0.6954	0.7901	0.8321	0.9388	1.0000	0.7475
Zhejiang	0.4405	0.4593	0.4971	0.5177	0.5716	0.6255	0.6669	0.7067	0.5607
Anhui	0.6490	0.5836	0.6342	0.6353	0.6849	0.7222	0.7989	0.8909	0.6999
Fujian	0.5776	0.5814	0.6686	0.6636	0.7800	0.8859	0.9377	1.0000	0.7619
Jiangxi	0.4404	0.4708	0.5063	0.5320	0.5652	0.5504	0.5765	0.5997	0.5302
Shandong	0.6960	0.8981	0.8225	0.8942	0.9282	1.0000	1.0000	1.0000	0.9049
Henan	0.5575	0.5689	0.6053	0.7217	0.7407	0.7714	0.8446	0.8820	0.7115
Hubei	0.3793	0.3934	0.3927	0.4736	0.5180	0.5714	0.6552	0.7416	0.5156
Hunan	0.3586	0.4098	0.4710	0.5365	0.6023	0.6773	0.7349	0.8110	0.5752
Guangdong	0.7110	0.8390	0.8234	0.9089	0.9582	0.9855	0.9932	1.0000	0.9024
Guangxi	0.5795	0.6108	0.6589	0.7753	0.8580	0.7340	0.7844	0.8568	0.7322
Hainan	0.9044	0.9979	1.0000	0.8868	1.0000	1.0000	0.9729	1.0000	0.9703
Chongqing	0.3066	0.3397	0.3562	0.3797	0.3988	0.4345	0.5522	0.5618	0.4162
Sichuan	0.3824	0.4187	0.4890	0.5400	0.5948	0.7692	0.8560	0.8977	0.6185
Guizhou	0.5192	0.4863	0.4821	0.5048	0.5702	0.5768	0.5948	0.7067	0.5551
Yunnan	0.4944	0.4683	0.5855	0.6855	0.7120	0.6837	0.7902	0.8225	0.6552
Shaanxi	0.3866	0.3533	0.3919	0.4583	0.5039	0.5487	0.6523	0.6998	0.4994
Gansu	0.2551	0.2339	0.3027	0.2946	0.3325	0.3541	0.4056	0.4888	0.3334
Qinghai	0.3845	0.3611	0.3559	0.3710	0.3097	0.3493	0.3908	0.4381	0.3700
Ningxia	0.3886	0.3715	0.3971	0.4346	0.4243	0.4783	0.4929	0.4352	0.4278
Xinjiang	0.3446	0.2763	0.3295	0.3186	0.3393	0.3976	0.4346	0.4946	0.3669
Average	0.4755	0.4916	0.5327	0.5841	0.6192	0.6627	0.7125	0.7538	0.6040

(a) UEM scores of thirty provinces during eight years from 2005 to 2012 use a pooled data set (240 = 30 x 8 observations).

(b) All provinces showed the increasing trend in UEM during the eight years. This indicated that the Chinese government put effort on environmental protection, but still not efficient.

(c) Source: Sueyoshi & Yuan (2016).

Table 3A: Classification of UC, DC, RTD and DTR of 30 provinces in eight years

Province	2005				2006				2007				2008			
	UC	RTD	DC	DTR	UC	RTD	DC	DTR	UC	RTD	DC	DTR	UC	RTD	DC	DTR
Beijing	W	No	W	No	W	No	W	No	W	No	W	No	No	D	W	No
Tianjin	W	No	W	No	W	No	W	No	W	No	W	No	No	D	W	No
Hebei	No	D	S	N	No	I	S	N	No	D	S	N	No	D	S	N
Shanxi	No	I	W	No	No	I	W	No	No	I	W	No	W	No	W	No
Inner Mongolia	W	No	W	No	W	I	S	N	W	No	W	No	W	No	W	No
Liaoning	No	I	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Jilin	No	D	S	N	No	I	S	N	No	I	S	N	No	I	S	N
Heilongjiang	No	I	S	N	No	I	S	N	W	No	S	N	No	D	S	N
Shanghai	W	No	W	No	W	No	W	No	W	No	W	No	W	No	W	No
Jiangsu	No	D	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Zhejiang	No	D	S	N	No	D	S	N	W	No	S	N	S	N	S	N
Anhui	No	D	S	N	No	D	S	N	No	I	S	N	No	I	S	N
Fujian	S	N	S	N	S	N	S	N	S	N	S	N	S	N	S	N
Jiangxi	No	D	S	N	W	No	S	N	W	No	S	N	No	D	S	N
Shandong	No	D	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Henan	No	D	S	N	No	D	S	N	W	No	S	N	W	No	S	N
Hubei	W	No	S	N	No	D	S	N	W	No	S	N	W	No	S	N
Hunan	No	D	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Guangdong	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Guangxi	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Hainan	W	No	W	No	No	I	W	No	W	No	W	No	S	N	S	N
Chongqing	W	No	S	N	W	No	W	No	W	No	S	N	W	No	S	N
Sichuan	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Guizhou	W	No	W	No	W	No	W	No	W	No	W	No	W	No	No	I
Yunnan	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Shaanxi	No	I	S	N	No	I	S	N	No	I	S	N	No	I	S	N
Gansu	No	I	W	No	No	D	W	No	No	I	S	N	W	No	S	N
Qinghai	No	I	W	No	No	I	W	No	S	N	W	No	No	I	W	No
Ningxia	W	No	W	No	S	N	W	No	W	No	W	No	W	No	W	No
Xinjiang	W	No	W	No	W	No	W	No	W	No	W	No	W	No	S	N

(a) W stands for weak, S stands for strong, N stands for negative, I stands for increasing, D stands for decreasing.
(b) Most provinces in east coast China and four municipals belonged to no or weak in UC and decreasing or no in RTD and even though Hainan had weak or no UC, but increasing RTD in year 2006, 2010 and 2012. Therefore, the Chinese government should invest and develop Hainan in terms of economy.
(c) Most of the central provinces had weak or no UC with no or decreasing RTD except Hubei.
(d) Even though some of the northeast and north provinces had some no UC with increasing RTD before 2008, all of the provinces had weak or no UC with no or decreasing RTD.
(e) Even if the UC of all western provinces such as Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang is weak or no, all of them had no UC with increasing RTD. The Chinese government should reinforce the development of western China.
(f) Most provinces all over the China including east coast China, central China, northeast and north China have strong potential to reduce the pollutions with green technology innovation because they have strong DC with negative DTR The Chinese government should invest green technology to provinces in east coast, central China, northeast and north China, as well as Xinjiang in western China.
(g) There are two types of provinces having weak DC with no DTR, which indicates the low level of potential for pollution mitigation. One type is big municipals such as Beijing, Tianjin and Shanghai. The other type is western China.
(h) Source: Sueyoshi & Yuan (2016)

Table 3B: Classification of UC, DC, RTD and DTR of 30 provinces in eight years

Province	2009				2010				2011				2012			
	UC	RTD	DC	DTR	UC	RTD	DC	DTR	UC	RTD	DC	DTR	UC	RTD	DC	DTR
Beijing	No	D	W	No	W	No	W	No	No	D	W	No	W	No	W	No
Tianjin	No	D	W	No	W	No	W	No	W	No	W	No	No	D	W	No
Hebei	No	D	S	N	No	D	S	N	W	No	S	N	W	No	S	N
Shanxi	W	No	W	No	W	No	S	N	W	No	S	N	W	No	S	N
Inner Mongolia	W	No	W	No	W	No	S	N	W	No	S	N	W	No	S	N
Liaoning	No	D	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Jilin	No	I	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Heilongjiang	No	D	S	N	No	D	S	N	No	D	S	N	No	D	W	No
Shanghai	S	N	W	No	S	N	W	No	No	D	W	No	No	D	W	No
Jiangsu	S	N	S	N	W	No	S	N	No	D	S	N	No	D	No	D
Zhejiang	S	N	S	N	S	N	S	N	S	N	S	N	W	No	S	N
Anhui	No	I	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Fujian	S	N	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Jiangxi	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Shandong	No	D	S	N	No	D	S	N	No	D	S	N	W	No	S	N
Henan	W	No	S	N	W	No	S	N	W	No	S	N	W	No	S	N
Hubei	No	D	S	N	W	No	S	N	S	N	S	N	S	N	S	N
Hunan	W	No	S	N	W	No	S	N	W	No	S	N	No	D	S	N
Guangdong	W	No	W	No	S	N	S	N	W	No	S	N	No	D	S	N
Guangxi	No	D	S	N	No	D	S	N	No	D	S	N	No	D	S	N
Hainan	W	No	W	No	No	I	S	N	No	D	W	No	No	I	S	N
Chongqing	W	No	S	N	W	No	S	N	No	D	S	N	W	No	S	N
Sichuan	No	D	S	N	No	D	W	No	No	D	S	N	No	D	S	N
Guizhou	W	No	W	No	W	No	W	No	W	No	W	No	No	I	W	No
Yunnan	W	No	S	N	W	No	S	N	W	No	S	N	No	D	S	N
Shaanxi	No	I	S	N	No	I	S	N	No	I	S	N	No	I	S	N
Gansu	No	I	S	N	No	I	S	N	No	I	S	N	No	I	W	No
Qinghai	No	I	W	No	No	I	W	No	No	I	W	No	No	I	W	No
Ningxia	W	No	W	No	No	I	W	No	No	I	W	No	W	No	W	No
Xinjiang	W	No	S	N	W	No	S	N	W	No	S	N	No	I	S	N

(a) W stands for weak, S stands for strong, N stands for negative, I stands for increasing, D stands for decreasing.
(b) See the notes (b)–(g) in Table 3A.
(c) Source: Sueyoshi & Yuan (2016).

Discussion

This study obtains a data set from National Bureau of Statistics of the People's Republic of China (http://www.stats.gov.cn/tjsj/). Using the data set, this study examines thirty provinces of China including four well-developed municipalities directly under the central government, which are Beijing, Shanghai, Tianjin and Chongqing, but excluding Tibet, Hong Kong and Macau because of our limited data accessibility on the three regions during 2005–2012. This study utilizes four desirable outputs: Gross Regional Product (GRP), value-added of the primary industry, the secondary industry and the tertiary industry, three undesirable outputs: PM10, SO_2 and NO_2, five inputs: investment in energy industry, coal consumption, oil consumption, natural gas consumption and electricity consumption.

Table 1 summarizes the UEN(UC) scores of the thirty provinces. The increasing trend of UEN(UC) from 2005 to 2012 indicated an improving trend in terms of their regional economies. Besides Beijing, most of the provinces with a high level of UEN(UC), were found in the east coast of China. They were Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan, Jiangxi and Hunan. In Chinese history, the east coast was first developed due to convenient connection with other countries. Then, the central China, including Anhui, Henan and Hubei provinces exhibited UEN(UC) at the level of about 0.7. In a descending order, the northeast and northern China, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin and Heilongjiang had UEN were rated from 0.4027 to 0.6749, being about 0.5 on average. The worst part of China in terms of economic performance was western China including Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The average UEN(UC) of these provinces was only about 0.35. In particular, the UEN(UC) of Xinjiang exhibited 0.2919 in the magnitude.

Table 2 summarizes the degree of UEM(DC) on thirty provinces during eight years. All provinces showed an increasing trend in UEM(DC) during the eight years. This indicated that the Chinese government put effort on environmental protection, but being still not efficient. Specifically, most of the east coast provinces with good economic performance still performed best in their environment protection such as Shandong, Jiangsu, Fujian, Guangdong, Guangxi and Hainan. As mentioned previously, large provinces such as Beijing, Shanghai and Zhejiang performed poorly on environment protection but with good performance on economy. The UEM(DC) of northeast and north provinces was about 0.6 on average. The UEM(DC) of western China was about 0.4 on average.

Table 3A and 3B summarizes UC, RTD, DC and DTR on the thirty provinces. In 2005 and 2012, many Chinese provinces were rated as weak or no in UC and no or decreasing RTD. See Beijing. The result indicated an economic growth limit on those provinces. Exceptions could be found in Liaoning, Shaanxi, Gansu and Qinghai, which exhibited no UC and increasing RTD. They had an economic growth potential. In contrast, most of Chinese provinces were rated as strong in DC and negative in DTR, so indicating that they had a potential to reduce the level of air pollution by eco-technology development. Exceptions found could be municipalities such as Beijing, Tianjin and Shanghai, for example. They were rated weak UN and no DTR, so implying that they did not have a potential to improve the level of air pollution by eco-technology at that time.

The Chinese government has long paid attention to the rapid economic development, but not making a major policy effort to reduce its air pollution. As a result, the current level of environment was not good enough to attain the status of social sustainability. Moreover, regional imbalance still exists in China. The east coast provinces developed the best with the highest level of UEN(UC) and UEM(DC), followed by the central, northeast and north regions, which was close to Beijing. The worst performance on both economy and environment protection was still western provinces after the western developing programs. Most of resources in China were mainly allocated to large cities, especially the Chinese capital Beijing. The northeast and north regions have performed insufficiently even though they are so close to Beijing. Because of the rapid development on economy in large cities such as Beijing and Shanghai, even if the Chinese government tried to improve their environment protection, the pace could not catch up with their pollutions creations in air.

From the perspective of the international concern on climate change, it is necessary for us to raise another serious policy issue on China. As first discussed by Sueyoshi and Yuan (2015), the Chinese government has structurally a limited governance capability to reduce the amount of CO_2 emission. Sueyoshi and Yuan (2016) discussed that the government should allocate resources to small provinces so that China can reduce the industrial and regional imbalances. Also, large provinces need strict regulation on traffic control and a fuel mix shift from coal combustion to natural gas and renewable energies. This study focused more on energy planning and the role of government.

We know that the central government has previously proposed many environmental plans, but local governments have not maintained enough governance capabilities to monitor and control the amount of GHG emission in provinces. The reason is that energy firms are usually under public ownership, being able to call “China Inc.” It is easily envisioned that local governments do not have the monitoring power to reduce the level of GHG emissions that have been produced by public companies in energy sectors and other industrial sectors. Therefore, the Chinese government should consider the privatization. The government should transfer the public ownership to private ownership and only conduct the monitoring function. The government can do a better job in regulation if there is no interest conflict. In other words, if any private energy firm violates the law or regulation, the government can punish the firm seriously without harming the government’s benefit or revenue. Once the firms realize that they may lose huge profit in risk even face bankruptcy, no firm will take the risk to violate the law or regulation in energy planning. Also historical result of privatization tells us that privatization consistently improves efficiency in competitive industries. The more competitive the industry is, the greater improvement in profitability and output. The increased economic growth can further benefit the income imbalance of China.

Conclusion

This study discussed the concept of UC under natural disposability and DC under managerial disposability from their economic and methodological implications on social sustainability development. Considering the two groups of disposability concepts, this study compared between RTD under UC and DTR under DC. These new scale measures (i.e., RTD and DTR) can be considered as extended concepts of Returns to Scale (RTS) and Damages to Scale (DTS).

This study applied the methodology to Chinese economic and environmental assessment for its future economic and energy planning for social sustainability development. This study identified three important concerns: First, the Chinese government had historically paid attention to the economic prosperity, but not paying serious attention on air pollution prevention. Second, there was an increasing trend in improving the two components (i.e., economic and environmental performance) for social sustainability. Third, the economic and energy policy concerns had been focused upon well-developed municipalities (e.g., Beijing and Shanghai), not small provinces, in China. Therefore, the privatization is necessary for central government of China (i.e., from public to private energy firms). It can not only improve the energy management and monitoring by government, but also increase the economic efficiency in market so that GDP can be increased. In further, the increased economic growth can better the economic imbalance of China.

In conclusion, it is important to note that this study is based upon the work of Sueyoshi & Yuan (2016). It is hoped that this study makes a contribution in DEA environmental assessment. We look forward to seeing future extensions as discussed in this study.

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