Running Efficiency and S&T Contribution to Regional Wastes' Treatment in China based on Parallel and Two-stage DEA models

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Abstract: In this study, we apply parallel and two-stage DEA models to measure the running efficiency and S&T contribution to regional wastes' treatment in China. The process of harshly development in industry often sacrificed natural living environment of human being. Because of greenhouse effect, poor air and water quality, improper disposed solid waste and other environmental pollution problems, regional environment are bearing tremendous pressure. To relieve pressure on environment and keep sustainable development in China, decision makers begin to focus on the optimal measures of ecological environment. A novel parallel and two-stage DEA models were applied to evaluate the efficiency of regional wastes' treatment in China. While the status of wastes can be divided into three types, i.e. waste water, gas and solid wastes, we classified different types of treatments into three modes. Then, the multiple parallel DEA methodology is applied to calculate the treatment efficiency of these three modes of wastes treatment in 30 provincial regions in China. Taking S&T inputs as a pivotal effect on wastes' treatments, two-stage DEA model was applied to calculate S&T contribution rate to wastes' treatment in 30 provincial regions in China. Based on the calculation results, decision making information can be drawn for each region in China and.

Keywords: Ecological regions, overall efficiency, parallel DEA, sub-system efficiency, treatments of wastes, two-stage DEA

INTRODUCTION

Since 1970s, the old Soviet mode had been applied which mainly enlarged the inputs, especially labor and capital, in China and had already pushed China's economy development. In that process, natural environment and limited resources were sacrificed to pursue economy's rapid development. With the influence of global greenhouse effect and serious pollution, decision makers began to transfer traditional production mode into environmental friendly development mode and emphasis on the capability of wastes' treatments. Generally, based on the status of wastes, we can classify wastes into three different modes, i.e., waste gas, waste water and solid wastes. The treatments of the three types of wastes are pivotal measures to build regions with more environmentally friendly.

Water quality management issues were discussed in Oregon, USA and proposed constructive measures to enhance the capability of waste water's treatment (Sharon et al., 1991). At the same time, other two types of wastes, waste gas and solid wastes, also take important roles in ecological environment. A coordination of Energy-Economy-Environment System should be expressed by the close relationship between energy, economy and environment (Heshan et al., 2011). The evaluation of wastes' treatment should be applied to identify the development level of ecological optimization. Many statistical methodologies can be applied to calculate ecological indicators (Paul, 1996). In fact, the treatment processes of waste gas, waste water and solid wastes are parallel systems where little interaction exists among those three systems. At the same time, all three processes cover the major aspects of wastes' treatment. Based on the parallel structure of three types of wastes' treatment, we applied parallel DEA to calculate the running efficiency and provide regional information of wastes' treatments to the decision makers. To identify the effect of S&T on wastes' treatment, two-stage DEA model was applied to measure the contribution of S&T to wastes' treatments.

RUNNING EFFICIENCY OF WASTES' TREATMENTS

Structure and indexes of wastes' treatments: In general, we candise all of wastes in three types, denoted as waste gas, waste water and solid wastes. To optimize the eco-environment, we also should apply
corresponding treatment measures in these three types
wastes (Xiong et al., 2007; Kai-ya et al., 2005).
Because three types of wastes are existed in different
forms, the treatment of them is expressed as parallel
measures. Then, we divided the optimization of eco-
environment into three parallel processes, i.e., waste
gas treatment, waste water treatment and solid wastes'
treatment (Yong and Qing, 2005). If we take each of
waste treatment as a sub-system, there are multiple
indexes can be listed to measure the efficiency of each
process of waste treatments (Yao-bin et al., 2005) in the
view of multiple inputs and outputs. The indexes can be
shown on Table 1.

For waste gas treatment, we use 1 input and 4
outputs index to interpret the sub-system's efficiency.
For waste water treatment, we design 2 inputs and 2
outputs index to explain the efficiency of sub -system.
For solid wastes' treatment, we apply 1 input and 3 outputs
to measure the sub-system's efficiency.

**Multiple parallel DEA model:** DEA model CCR
(Charnes et al., 1978) was applied an optimal linear
programming formula to calculate efficiency of DMUs.
Suppose we have n DMUs and that kth DMU, (k = 1,
2, ..., n) has m inputs, denoted as \(x_{ik}\) (i = 1, 2, ..., m)
and s outputs, denoted as \(y_{rk}\) (r = 1, 2, ..., s). The
traditional CCR DEA model can be expressed by the
following formula (1):

\[
E_i = \max \sum_{r=1}^{s} u_r y_{rk} \quad \text{subject to} \quad \sum_{r=1}^{s} v_r x_{ik} = 1 \\
\sum_{r=1}^{s} v_r y_{rk} - \sum_{i=1}^{m} \sum_{j=1}^{s} v_{ij} x_{ij} \leq 0, j = 1, ..., n \\
u_r, v_r \geq 0, r = 1, ..., s, i = 1, ..., m
\]

By calculating with DEA models, the optimal
weights can be allocated for each DMU, denoted as
\(v^* = (v_{1j}^*, v_{2j}^*, ..., v_{mj}^*)\) and \(u^* = (u_{1j}^*, u_{2j}^*, ..., u_{mj}^*)\), which
guarantee the kth DMU with the maximum efficiency
value. If the objection of model (1) equals to 1, then the
DMU is denoted as DEA efficient DMU. If the
objection of model (1) is less than 1, then the DMU is
denoted as DEA inefficient DMU. DEA models have
obvious advantages in measure the performance of
multiple inputs and outputs system. However, traditional
DEA models take system as a black box and ignore the
internal structure of system.

In general, the inside of DMU can be classified in
different structures and the internal structure can affect
the overall efficiency of whole system. For each of sub-
systems, its efficiency has close relationship to overall
efficiency. In this study, we will use the DEA model to
deal with parallel sub-system structures.

To overcome the shortcomings of traditional DEA
models, parallel DEA model (Chiang, 2009) was
proposed for measuring the relationship between sub-
systems and DUM. Firstly, we will explain the parallel
structure. For each of DMUs, there are q sub-systems,
denoted as sub-system 1, sub-system 2, ..., sub-system q.
For each of sub-systems, we use \(X_p^j\) and \(Y_p^j\) to express the
rth input and rth output, respectively, of the pth sub-
system. The relative inefficiency of a set of n DMUs, each has q parallel sub-systems can be calculated by
defining formula:

\[
\min \sum_{p=1}^{n} z_p^* \\
\sum_{p=1}^{n} z_p^* = 1; \sum_{p=1}^{n} u_p^* y_{pk}^* - \sum_{p=1}^{n} v_p^* x_{pk}^* + s_{pk}^* = 0 \\
\sum_{p=1}^{n} u_p^* y_{pk}^* - \sum_{p=1}^{n} v_p^* x_{pk}^* \leq 0 \\
u_p^*, v_p^*, s_{pk}^* \geq 0, p = 1, 2, ..., q; \, j = 1, ..., n; \, j \neq k; \, r = 1, ..., s, i = 1, ..., m
\]

The above model (2) should be calculated for n
times to obtain the inefficiency slacks of systems as well
as their sub-systems. However, the inefficiency
slacks is not equal to inefficiency scores because is not
equal to 1 for kth DMU with wth sub-systems.
Therefore, the inefficiency score should be calculated
by \(S_{pk}^w\) should be divided by \(\sum_{p=1}^{n} v_p X_{pk}^w\) and the efficiency
score should be:

\[
1 - \frac{S_{pk}^w}{\sum_{p=1}^{n} v_p X_{pk}^w}
\]

**Calculation and results:** Based on those indexes listed
on Table 1, we collect 30 provinces corresponding
The other 7 regions, i.e., Jiangxi, Guizhou, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang, located on the west part of China. Those regions' development of industry is lagged comparing to other eastern regions.

**S&T CONTRIBUTION TO WASTES’ TREATMENTS**

With the rapid change and development of society, S&T has become the pivotal power for pushing the development of regional economy. However, the traditional regional strategy was focus on the development of industry but ignore the protection of environment. Therefore, the traditional S&T inputs were designed for stimulate the development of industry (Wang et al., 1997). With the development of regional eco-construction, more of S&T inputs for optimizing eco-environment are proposed. In the view of regional eco-construction, the impact of S&T inputs on environmental emission and treatment were measured in this study. Based on the chain relationship between S&T inputs, environmental emission and environmental treatment, additive two-stage DEA model was applied to calculate the impact efficiency of S&T inputs on environmental emission and treatment (Rongchao, 2007). At the same time, we can obtain the impact relationship between S&T inputs and regional eco-environmental optimization.

**Basic structure of S&T’s effect on wastes' treatment:** To identify the influence of S&T to eco-environment optimization, we divided the whole process into two connected stages. Taking related S&T indexes as inputs and wastes emission indexes as outputs in the first stage, we can identify the "wastes producing stage" the first stage. Then, the second stage is "wastes' treatments stage" which takes wastes emission as inputs and treated wastes as outputs and corresponding indexes is same as the indexes mentioned in Section II. The wastes emission indexes are same as the inputs on Table 1. Therefore, the two stages are connected by intermediate indexes. The structure can be shown in Fig. 1.
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Because the intermediate indexes and outputs have been identified on Table 3, we will propose S&T indexes as inputs. Based on the principle of scientific, comprehensive, operational and obtainable and referenced on related references, six indexes can be listed as the S&T indexes in the left column on Table 3.

Two-stage DEA methodology: We suppose there are DMUs and each DMU (j = 1, 2, …, n) has m inputs, denoted as \( x_{ij} (i = 1, 2, \ldots, m) \). Through the first stage, we get s outputs, denoted as \( y_{ijk} (k = 1, 2, \ldots, s) \). Because the second system follows the first system, the outputs of the first system become the inputs of the second system. Through the second system, there are p outputs produced, denoted as \( y_{ijk} (k = 1, 2, \ldots, p) \).

A two-stage DEA model was proposed based on CRS (Constant Return to Scale) model (Chen et al., 2009; Sexton and Lewis, 2003), which can be expressed as follow for DMU as formula (3), where \( \theta \) is the efficiency score at the first stage’s efficiency (\( \theta_o \)) or the second stage’s efficiency (\( \theta_i \)).

\[
\theta_o = \max \left\{ \frac{\sum_{j=1}^{n} \pi_j z_{ij}}{\sum_{j=1}^{n} \sigma_j x_{ij} \geq \alpha} \right\} \geq \beta
\]

The efficiency for the second stage then is calculated as:

\[
\theta_i = \theta_o - \frac{w_1 \cdot \theta_i}{\theta_o}
\]

For the second stage’s efficiency (\( \theta_i \)), we can calculate from model (6):

\[
\theta_i = \max \left\{ \sum_{j=1}^{n} \mu_j y_{ij} \right\}
\]

The efficiency for the first stage then is calculated as:

\[
\theta_o = \theta_i - w_2 \cdot \theta_i
\]

Calculation and results: Using the corresponding panel data of 30 provincial regions, we can calculate the contribution rate of S&T in both stages, denoted \( \theta \) as S&T contribution rate in wastes production stage, \( \theta \) as wastes treatment capability and \( \theta \) as S&T contribution rate in wastes production stage. All of required statistic data are collected from 2011 China Statistic Year Book, 2011 Chinese Environmental Statistic Year book and 2011 Cities Statistic Year Book in China. By used additive two-stage DEA model, we can get the calculation results on Table 4.

By using two-stage DEA model, we can get the S&T contribution rate to wastes' production and wastes' treatment. \( \theta \) expressed the effect of S&T to wastes' production, where the more this value the more influence on environmental pollution.
Based on the value of $\theta^*_1$, there are 25 provinces whose corresponding value larger than 0.6. Because S&T inputs can improve the efficiency of production and enlarge scale in enterprises, the productivity is enhances in multiple aspects. At the same time, emission of wastes is increased in the same process. The most serious provincial regions are Shanghai, Anhui, Shandong, Guangdong, Guizhou and Ningxia. Therefore, for these regions, governments should apply measures on strengthen the pollution treatments and energy saving capability in enterprises.

Based on the value of $\theta^*_0$, Shanghai has the highest value, i.e. 1 and other regions' values are less than 1. $\theta^*_0$ Means the positive effect on wastes' treatment. Therefore, the overall contribution of S&T to wastes' treatment is not high. There are five regions whose values are less than 0.6 where S&T has a weak influence on wastes' treatment. To enhance the contribution of S&T to environmental purification, government should propose more S&T project and enlarge investment in regional environmental construction. Moreover, we should increase more S&T human resource and grants in the research filed of environmental science and ecological sciences.

**CONCLUSION**

Based on the parallel DEA calculation results, there are 16 regions' efficiencies are less than 1. To optimize eco-environment and keep sustainable development mode in China, we should empower the wastes' treatments capability in the next few years. At the same time, we also should pay attention to the average level of efficient values that all of efficiency values are more than 0.9. The meaning is the gaps between different regions in eco-environmental optimization are not very huge. Therefore, it is feasible to optimize the overall eco-environment in China. Based on the calculation results of two-stage DEA model, S&T contribution to wastes' treatments in Shanghai is ranked on the top one among 30 provincial regions. Therefore, Shanghai should be the benchmark of other regions.

In the past 30 years, we didn't care too much about our eco-environment which produced some pollution and a lot of wastes. How to enhance the capability of deal with those wastes should be important measures to make our environment friendly. Now, Chinese government has already recognize the importance of protection on eco-environment and increased inputs to support the treatments of wastes. Governments should propose specific measures in different provincial regions based on their corresponding evaluation results. By referencing on the calculation results, government can get eco-environmental optimization levels in 30 regions and make corresponding measures to enhance optimization capability of eco-environment in China.
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