

Eco-efficiency Evaluation to Chinese Textile Mills

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Abstract — Ecological efficiency evaluation is an important task of central or local governments for environment protection and sustainable development. Data Envelopment Analysis is a typical mathematical tool used in ecological efficiency evaluation, and a lot of DEA models are proposed. The current paper uses the ecological Shannon DEA procedure based upon the existing study to obtain an ecological comprehensive efficiency score for each of a group of Chinese textile mills. The results seem reasonable since they integrate the results of existing relevant DEA model.

Keywords-data envelopment analysis (DEA); undesirable output; eco-efficiency; Shannon's entropy

1. Introduction

In the recent year, environmental protection has been emphasized in China's economic policy. Many provinces, especially the richest provinces, have closed many firms which perhaps emit a great deal of pollutants. However, the poorest provinces have no enough incentive to do that. Moreover, to enhance GDP and economic level, some of the poorest provinces are eager to invite those closed firms to reopen in their own regions. Thus the environmental destroy will probably happen in those undeveloped provinces in China.

In computation, the eco-efficiency of a specific activity or organization is usually measured by the ratio of two indices. The numerator is measured by the added value in economic and environmental aspects, such as profit, income, service, employment, environment improvement, GDP, etc. The denominator is expressed as the added cost in economy and added harm to environment, including, for example, investment, expenditure, energy, emitted carbon dioxide and waste water, and so on. In practice, for various evaluated units in varying scenarios, the numerator and denominator are usually chosen variously, and the computation forms for the eco-efficiency also vary a lot. For example of eco-efficiency analysis of power plants in one European country by Korhonen and Luptacik (2004), the numerator is the quantity of electricity generation, and the denominator includes the total costs and the undesirable outputs (dust, nitrogen oxides and SO₂).

In the eco-efficiency evaluation, Data envelopment analysis (DEA) has been widely accepted as an effective tool. DEA is a tool designed to provide a relative efficiency score for each member of a group of decision making units (DMUs). The current paper tries to use the Shannon DEA model to evaluate the ecological performance of 25 Chinese textile mills with one key objective to deal with the undesirable outputs in eco-efficiency framework.

The rest of the paper unfolds as follows: In section 2 introduce the existing DEA methods to deal with undesirable outputs in eco-efficiency evaluation which would be used in the Shannon DEA procedure in Section 3. Subsequently in Section 3, we introduce the Shannon's entropy DEA models and the

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comprehensive efficiency scores; Section 4 illustrates a real example in China to study the ecological performance of 25 textile mills. Finally, conclusions and further directions are given in the last section.

2. Review on the existing methods

Suppose there are n independent homogeneous decision making units. For the j th DMU, i.e., DMU_j ($j=1, \dots, n$), it consumes m inputs $X_j=(x_{1j}, x_{2j}, \dots, x_{mj})$ to produce s desirable (good) outputs $Y_j=(y_{1j}, y_{2j}, \dots, y_{sj})$ and t undesirable (bad) outputs $Z_j=(z_{1j}, z_{2j}, \dots, z_{tj})$. In general, an effective management of ecological system aims to produce desirable outputs as much as possible and undesirable outputs as little as possible if keeping inputs unchanged.

The DEA research on dealing with undesirable outputs can be mainly divided into four groups as follows:

The first group is the hyperbolic measure approach introduced by Färe et al (1989). Färe et al (1989) propose two types of measures with two extra constraints attached. The first is called reciprocal measure which requires the inputs unchanged, and the second is called hyperbolic measure which tries to decrease inputs at the same extent as the undesirable outputs.

The second group of method is much simpler, just regarding the undesirable outputs as inputs directly such as Hailu and Veeman (2001).

The third group is about the data transformation function approach including the additive transformation function such as Ali and Seiford (1990) and Berg et al. (1992) and the multiplicative transformation function such as Lovell et al. (1995) and Athanassopoulos and Thanassoulis (1995).

The last group is about directional distance function approach proposed by Chung et al (1997) and Fare and Grosskopf (2004).

As discussed above, the researchers have made a great deal of contributions to deal with undesirable outputs in DEA framework. However, which model should be used in a specific scenario or how about the discriminability of a given DEA model is hard to decide in practice. The current paper uses the ecological Shannon DEA procedure based upon the existing study to obtain an ecological comprehensive efficiency score for each of a group of Chinese textile mills.

3. Shannon DEA PROCEDURE

Soleimani-Damaneh and Zarepisheh (2008) developed a Shannon DEA procedure to generate a comprehensive efficiency score for each DMU. The following paragraphs show the six-step procedure proposed by them:

Step 1: Calculate the efficiency matrix $[E_{jk}]_{n \times K}$ in (1) as follows:

$$\begin{matrix} & M_1 & M_2 & \dots & M_K \\ DMU_1 & \left[\begin{matrix} E_{11} & E_{12} & \dots & E_{1K} \\ E_{21} & E_{22} & \dots & E_{2K} \\ \vdots & \vdots & & \vdots \\ E_{n1} & E_{n2} & \dots & E_{nK} \end{matrix} \right. \\ DMU_2 & \\ \vdots & \\ DMU_n & \end{matrix} \quad (1)$$

In Matrix (1) the element E_{ji} in (1) means the efficiency score of the j th DMU originated from the i th model. Specially K means the number of model types introduced in the previous section. We employ 8 types of DEA models in computation in the next section, so $K=8$ in the current paper.

Step 2: Let $e_{jk} = E_{jk} / \sum_{t=1}^n E_{tk}$ ($k = 1, 2, \dots, K$) to normalize the efficiency Matrix $[E_{jk}]_{n \times K}$.

Step 3: For each model used, M_k , calculate entropy $f_k = -(\ln n)^{-1} \sum_{j=1}^n e_{jk} \ln(e_{jk})$.

Step 4: For model M_k , calculate the degree of diversification as $d_k = 1 - f_k$.

Here, d_k is an indication to represent the discriminability of a DEA model. Soleimani-Damaneh and Zarepisheh (2008) have proven that the larger value of d_k means the more distinct discriminability of the model. In detail, if a DEA model induces equal efficiencies for all DMUs, i.e., the DEA model has no discriminability to those DMUs, the resulting d_k equals to the smallest value as 0. Accordingly, we can use d_k to describe the importance of the model M_k .

Step 5: Calculate the weight W_k for the model M_k in the comprehensive efficiency score by normalizing the value d_k , i.e., let $W_k = d_k / \sum_{k=1}^K d_k$ and $\sum_{k=1}^K W_k = 1$.

Step 6: Calculate the comprehensive efficiency score $\theta_j = \sum_{k=1}^K W_k E_{jk}$, $j = 1, 2, \dots, n$.

4. Eco-efficiency evaluation to TEXTILE mills

In the current paper there are four input/output variables involved. The inputs include labor and capital, and desirable output as textile products while undesirable output as pollutant. The authors can provide the detailed input and output data set to readers.

Different from the previous studies, we use the Shannon DEA procedure to examine all of the models to generate a comprehensive efficiency score, and use it to appraise the eco-efficiency of the 25 Chinese textile mills. In fact, the Shannon DEA procedure used in the current paper is still different from the original form in Soleimani-Damaneh and Zarepisheh (2008). We use different models while Soleimani-Damaneh as Yang et al (2009) while differently Zarepisheh(2008) use different DMU sets.

Since many researchers have proposed a great number of DEA models to appraise the relative efficiencies for decision units with undesirable outputs, we can first obtain the efficiency scores of 25 textile mills according to the 8 models as reported in Table (1):

TABLE 1. EFFICIENCY SCORES BY THE 8 DEA MODELS

NO.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0.754	0.612	0.497	0.75	0.814	0.569	0.824	0.877
2	0.726	0.602	0.456	0.707	0.667	0.528	0.667	0.757
3	0.725	0.672	0.494	1	1	0.529	1	1
4	0.777	0.616	0.404	1	1	0.476	0.98	1
5	0.757	0.608	0.529	0.675	0.907	0.576	0.767	0.918
6	0.714	0.581	0.432	0.715	0.439	0.504	0.446	0.667
7	0.957	0.927	0.661	0.969	0.653	0.793	0.597	0.923
8	0.769	0.628	0.521	0.967	0.982	0.588	1	0.994
9	0.958	0.909	0.909	0.961	0.907	0.918	0.908	0.964
10	0.7	0.533	0.473	1	0.840	0.492	0.783	0.856
11	0.846	0.729	0.689	1	0.896	0.717	0.822	0.937
12	0.814	0.699	0.614	0.801	0.631	0.663	0.635	0.805
13	1	1	1	1	1	1	0.991	1
14	0.937	0.889	0.849	1	1	0.876	1	1
15	1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1
17	0.8	0.673	0.578	0.912	0.854	0.641	0.846	0.888
18	1	1	1	1	1	1	1	1
19	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	1	1
21	0.74	0.601	0.473	1	1	0.545	1	1
22	0.829	0.679	0.679	1	1	0.688	0.678	1
23	0.817	0.793	0.204	1	1	0.638	0.66	1
24	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1

By computation we also obtain the comprehensive efficiency scores for all textile mills which are reported by Table 2. There are 6 textile mills being comprehensively DEA efficient. Traditional approaches can't give a clear ranking for all textile mills in ecological evaluation, since the ranking orders for any textile mills in the 8 models are not stable. The comprehensive efficiency scores contain the information about all efficiency scores in those original models as well as the importance of each model, so it is believable to some extent.

TABLE 2. COMPREHENSIVE EFFICIENCY SCORES (CESS)

No.	CES	Rank	No.	CES	Rank
1	0.694	20	14	0.941	9
2	0.607	24	15	1	1
3	0.798	13	16	1	1
4	0.761	16	17	0.746	17
5	0.715	21	18	1	1
6	0.497	25	19	1	1
7	0.731	19	20	0.996	8
8	0.789	14	21	0.77	15
9	0.919	10	22	0.8	12
10	0.668	22	23	0.74	18
11	0.8	11	24	1	1
12	0.662	23	25	1	1
13	0.998	7			

5. Conclusions

There are a great number of DEA models are proposed to deal with ecological efficiency problems with undesirable outputs. However, which model should be used in a specific scenario or how about the discriminability of a given DEA model is hard to decide in practice. The current paper uses the Shannon DEA procedure, and establishes a framework to synthetically appraise the ecological systems with undesirable outputs. For each decision unit, a comprehensive efficiency score can be obtained from the ecological Shannon DEA procedure. The comprehensive efficiency score is acceptant because it contains a lot of necessary information, including efficiency scores in all of original models, and the importance of each model.

The paper examines the ecological evaluation to 25 textile mills in China. To avoid the potential ecological disaster, China government implements National Environment Protection Strategy to improve environment quality. The current study can help to examine the ecological efficiencies of those textile mills, and help decision makers to constitute reasonable policy in the dilemma of the choice of economy increasing and environment protection. For example, the reasonable pollutant emission quota for each textile mill can be induced according to our results.

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