New Ratio DEA Software for Measuring Efficiency of Industrial Departments

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Abstract—**As the environmental problem becomes more and more serious in the development of society, it has drawn a lot of attentions from every government. Industry prompts the development of economy at the same time produces a lot of pollutions, such as smoke pollution and waste. Evaluating the efficiency of the departments of industry benefits district government to decide which departments should be developed in priority. In this study, the new ratio model in data envelopment analysis (DEA) is proposed and applied for evaluating the industrial departments of Chongqing City of China. Moreover, some suggestions are given.**

Index Terms—**Data envelopment analysis; Software; Industry; Economy; Environment**

I. INTRODUCTION

In recent years, as the global environment becomes warmer, the resource become poorer and other global problems arise, resources and environment increasingly become a focus for every country. China gains a huge development in economy, however, the low efficiency of using resource and heavy pollution become an serious obstacle for sustained development. In order to solve this problem, China provided a new plan of establishing source saving and environment harmony society, that is develop the economy under the condition of saving resource and improving environment in order to achieve the development of society.

Industry is a very important industry, and plays a critical role in developing the economy and improving the life of people. However, industry is also an industry of large consumption and large pollution. Different departments in industry will perform differently in these two factors, economy and environment. Choosing some suitable departments for development or as prior developing developments is always a very difficult thing for a district. Ecological efficiency is a good index for analyzing a system with economic and environmental factors and it has been largely applied. In this study, industry of Chongqing City in China is analyzed through data envelopment analysis (DEA) method.

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DEA is a non-parametric programming technique and has become more and more popular in evaluating the performance efficiency of a set of homogenous decision making units (DMUs). It was first proposed by Charnes, Cooper and Rhodes in 1978 [1] and extensively applied in multiple inputs and multiple outputs complex systems. Since the CCR model, there has been an impressive growth both in theoretical developments and applications of DEA. DEA researchers have developed a number of updated models, such as BCC model [2], additive model [3], multilevel models [4, 5], super efficiency models [6] and so on. At the same time, DEA has also been extensively applied in performance evaluation and benchmarking of hospitals, universities, cities, courts, business firms, and others, including the performance of regions, countries etc [7].

The first DEA model for dealing with the undesirable outputs problem was proposed by Färe et al. (1989) [8]. Since then, undesirable outputs' research has been largely extended and applied in many areas. The studies on this topic may be classified into several categories. One is direct approach which is based on Färe et al. (1989) where strong disposability of outputs is replaced by the assumption that outputs are weakly disposable. This direction has been largely extended [9. 10, 11, 12]. Another category is treating undesirable outputs as inputs for processing [13, 14]. This approach only needs the information whether the data have to be minimized or maximized, but it cannot reflect the real production process [15]. The last category contains non-linear monotonic deceasing transformation approach [16] and linear monotonic decreasing transformation [15]. Scheel applied the reciprocal of undesirable output ($f(u_i^k)=1/u_i^k$) as new outputs [16]. Seiford and Zhu added a positive and big enough scalar β_i to the reciprocal additive transformation of the undesirable output *i* ($f(u_i^k)=-u_i^k+\beta_i$) as new outputs [15].

Recently, you and Yan proposed a ratio model for dealing with undesirable outputs [17]. In this model, the undesirable outputs are not treated as both inputs and outputs. a penalty index is used instead of undesirable

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outputs. And the new outputs of the system are formed by the desirable output divided by the penalty index. This model has an advantage that the undesirable output in it does not solely favor the efficiency score as the other approaches mentioned above. Moreover, it evaluates the undesirable as well as the desirable outputs simultaneously.

The rest of this paper is organized as follows. Section 2 brief introduces the DEA and ratio model. The analysis of industrial departments of Chongqing city by ratio model is shown in Section 3. The conclusions are drawn in the last section.

II. RATIO DEA MODEL

Assume that there are *n* DMUs to be evaluated, where each DMU contains *s* different outputs and *m* different inputs. Denote the *i*th input and *r*th output for DMU_j ($j=1,2,...,n$) as x_{ij} ($i=1,2,...,m$) and y_{rj} ($r=1,2,...,m$) respectively. $x_{ij}\geq 0$, $y_{rj}\geq 0$ and each DMU must has at least one positive input and one positive output value. CCR model proposed by Charnes et al. (1978) was the first DEA model [1], which is shown as follows.

$$e^{CCR} = min\ \theta$$

$$\text{s.t.}\quad \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^{-} = \theta x_{i0}, i=1,2,...,m$$
$$\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^{+} = y_{r0}, r=1,2,...,s \tag{1}$$
$$\lambda_j \geq 0,\ j=1,2,...,n.$$

As discussed in the introduction section, there are several approaches for dealing with the undesirable problem. One is direct approach, such as treating undesirable outputs as inputs for processing. The other is indirect approach, such as non-linear monotonic deceasing transformation approach, linear monotonic decreasing transformation and ratio approach. Here, the ratio model as a very new and useful approach is applied. So it is discussed in details.

$$min\ \theta$$
$$s.t.\ \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^{-} = \theta x_{ij_0}, i=1,\cdots,m,$$
$$\sum_{j=1}^{n}\lambda_j o_{rj} - s_r^{+} = o_{rj_0}, r=1,\cdots,s,$$
$$\delta_j = \sum_{l=1}^{t}\beta_l u_{lj}, l=1,...,t,$$
$$o_{rj} = \frac{1}{\delta_j} y_{rj}, r=1,...,s,$$
$$\sum_{j=1}^{n}\lambda_j = 1,$$
$$\lambda_j, s_i^{-}, s_r^{+} \geq 0,\ j=1,...,n. \tag{2}$$

In this model, y_{rj} represents *r*th desirable outputs of DMU_j . u_{lj} represents *l*th undesirable outputs of DMU_j . β_l is the coefficient of u_{lj} , and it means penalty which is charged for producing the undesirable output u_{lj} . δ_j is the total punishment for DMU_j . o_{rj} is the new rth output of DMU_j which contained both the undesirable and desirable factors. The main focus of the ratio model is to transform undesirable output into the penalty. The large amount of the undesirable output has the larger penalty. the Because of this, the efficiency and the number of efficient DMUs by ratio model are properly adjusted, which is different from other models which tend to give the DMU a better efficiency score after taking into account undesirable factors,

III. EFFICIENCY OF THE INDUSTRIAL DEPARTMENTS

Chongqing is a very important municipality in China, which locates in the southwest of China and near by Sichuan province. In this section, thirty-six departments of industry in Chongqing are analyzed and some suggestions for development are proposed based on the results.

Figure 1. The map of China

According to the attributes of industry, we choose the coal, natural gas and electricity as inputs, industrial output value as desirable outputs, Volume of SO2 Discharged, Volume of Industrial Dusts and Fume Discharged, Industrial Waste Water and Industrial Solid Wastes as undesirable outputs. Because the department of production and supply of gas and Manufacture of Articles for Culture, Education and Sport Activities has no pollution, we emit these units in our analysis. The data is obtained from the Chongqing statistical yearbook of 2011, and is shown in Table 1.

From DMU 1 to DMU 36 represent Mining and Washing of Coal, Extraction of Petroleum and Natural Gas, Mining and Processing of Ferrous Metal Ores, Mining and Processing of Non-Ferrous Metal Ores, Mining and Processing of Nonmetal Ores, Processing of Food from Agricultural Products, Manufacture of Foods, Manufacture of Beverages, Manufacture of Tobacco, Manufacture of Textile, Manufacture of Textile Wearing

Apparel, Footware and Caps, Manufacture of Leather, Fur, Feather and Related Products, Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products, Manufacture of Furniture, Manufacture of Paper and Paper Products; Printing, Reproduction of Recording Media, Processing of Petroleum, Coking, Processing of Nuclear Fuel, Manufacture of Raw Chemical Materials and Chemical Products, Manufacture of Medicines, Manufacture of Chemical Fibers, Manufacture of Rubber, Manufacture of Plastics, Manufacture of Non-metallic Mineral Products, Smelting and Pressing of Ferrous Metals, Smelting and Pressing of Nonferrous Metals, Manufacture of Metal Products, Manufacture of General Purpose Machinery, Manufacture of Special Purpose Machinery, Manufacture of Transport Equipment, Manufacture of Electrical Machinery and Equipment, Manufacture of communication Equipment, Computers and Other Electronic Equipment, Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work, Manufacture of Artwork and Other Manufacturing, Recycling and Disposal of Waste, Production and Supply of Electric Power and Heat Power, and Production and Supply of Water respectively.

TABLE I
THE RAW DATA OF DEPARTMENTS OF INDUSTRY

Department	Coal （tons）	Natural gas(10000 cu.m)	Electricity (10000 kwh)	Industrial output value	SO2 Discharged (10000 tons)	Industrial Dusts and Fume Discharged(10000 tons)	Industrial Waste Water(10000 tons)	Industrial Solid Wastes(10000 tons)
1	16226097.98	1258.0	150625.74	2390359.1	0.815	0.448	0.666	96.528
2	0.000	5007.0	5087.04	518438.1	0.163	0.023	0.017	0.000
3	29854.160	199.0	4941.31	126958.7	0.384	0.064	0.007	0.880
4	565.000	0	335.30	29351.9	0.000	0.000	0.014	0.049
5	248956.980	13.96	37363.91	591725.8	0.039	0.156	0.037	2.438
6	96167.910	1740.02	31348.11	2418832.6	0.296	0.261	0.159	0.650
7	91873.250	2395.29	16272.51	739999.4	0.564	0.130	0.265	0.057
8	92841.500	1920.18	29792.81	861596.1	0.341	0.088	0.097	1.516
9	12557.790	798.96	6378.36	855624.9	0.054	0.006	0.021	0.071
10	250433.460	2074.08	60262.37	1349588.7	0.870	0.199	0.290	0.009
11	746.000	198.34	2771.82	259982.2	0.000	0.000	0.001	0.000
12	1207.290	142.39	4177.85	388946.5	0.016	0.000	0.030	0.000
13	21819.880	50.19	4135.47	104344.8	0.051	0.095	0.005	0.000
14	503.230	94.16	4537.52	354254.8	0.000	0.000	0.001	0.000
15	982906.160	1098.84	90018.87	832963.1	1.735	0.233	0.620	0.018
16	3864.730	469.77	9425.21	435598.1	0.000	0.000	0.003	0.000
17	552902.430	221.2	10042.14	388421.9	0.728	0.071	0.008	0.000
18	2689000.850	187578.03	485120.47	3844469.3	2.679	0.734	1.388	0.264
19	184086.290	5131.51	56806.620	1662397.9	0.832	0.145	0.239	0.086
20	1216.000	0	2117.00	54865.0	2.009	0.176	0.149	0.000
21	113978.640	696.32	21584.76	432770.2	0.135	0.038	0.016	0.000
22	26149.470	126.2	33399.05	688390.2	0.054	0.024	0.007	0.000
23	4687079.410	67564.760	490612.84	3130103.3	12.519	11.857	0.189	16.425
24	670669.540	25027.17	370969.70	3004524.9	2.610	0.620	0.308	1.152
25	249764.420	11008.04	529143.27	3179502.1	0.352	0.130	0.084	13.881
26	18051.010	3995.77	35992.09	1056006.2	0.091	0.038	0.082	0.000
27	49499.310	10170.19	94870.18	3253203.4	0.115	0.067	0.034	0.052
28	14923.400	1534.19	31890.27	1573082.0	0.009	0.005	0.176	0.000
29	120011.380	30762.7	343937.74	23230574.8	0.128	0.090	0.297	0.370
30	7381.720	1950.02	35448.58	3414958.2	0.095	0.020	0.023	0.000
31	250.000	364.71	8945.64	1064372.4	0.000	0.000	0.005	0.000
32	805.000	636.04	8494.14	713526.8	0.000	0.000	0.007	0.000
33	6072.940	12.70	1594.91	121502.1	0.008	0.000	0.002	0.052
34	3011.960	285.99	6628.48	163496.1	0.007	0.000	0.004	0.000
35	12601911.110	444.84	588270.97	3670799.6	26.057	3.807	0.715	0.000
36	0.000	1.53	54083.85	145931.5	0.000	0.000	0.054	0.000

Before applying the ratio DEA model, model (2), β_l should be determined first. According to the damage of different kinds of pollution, we set $\beta_1,...,\beta_4$ as 2, 1, 2 and 2 respectively. And the efficiency of the departments can be obtained by model (2). Owing to the number of DMUs is large, and we just show some representatives whose efficiency exceeds 0.1 in Table 2.

TABLE II
EFFICIENCY OF SOME REPRESENTATIVES DEPARTMENTS

DMU	2	4	11	14
Efficiency	0.81686	1	0.59221	1
DMU	16	31	32	36
Efficiency	0.15505	0.72445	0.12381	1

It is shown in table (2) that DMU 4, 14, 36 are efficient and the other DMUs are inefficient. In the inefficient DMUs, DMU2 and DMU31 have relatively high efficiency. Excluding these eight DMUs above, the rest DMUs have a very low efficiency. From these results, we suggest that Chongqing City should give more resource to develop DMU 4, 14, 36 and pay more attention to the very low efficient DMUs. These results give Chongqing a clear way to achieve the goal of establishing source saving and environment harmony society. First, it should invest more to the efficient departments so as to fully utilizing the limited resource, such as the department of Manufacture of Furniture and the department of Production and Supply of Water. Second, selectively develop some departments of high efficiency, such as Manufacture of Communication Equipment, Computers and Other Electronic Equipment. Third, appropriately supervise or limit some low efficient departments, which either prompt economy a little or bring heavy pollution, such as the department of Production and Supply of Electric Power and Heat Power. The department of Production and Supply of Electric Power and Heat Power is mainstay industry of Chongqing, so limiting its development may be unfeasible but supervision and encouraging them to take measures to control the pollution is very necessary. Fourth, support some technological departments even though they have a low efficiency now, such as .the department of Manufacture of Communication Equipment, Computers and Other Electronic Equipment, because these departments will have a strong competition ability from a long period.

IV. Conclusions

Environment problem has become a very important issue in the development of economy. Industry is a mainstay industry in economy. There are many departments in industry. So, evaluating these departments' efficiency is very useful to get known of their performance on economy and environment. Furthermore, the results benefit us to determine which departments should be developed in particular and which departments should care its environmental factors in time. Therefore, this work is very meaningful. As an extension, how to allocate resource to the departments of industry is also a very interesting topic. Besides of this, how to evaluate the departments when their data is stochastic is also a future work.

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