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Identification Desirable Congestion in Data Envelopment Analysis

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Abstract

The identification of undesirable congestion is important to avoid a cost increase and a shortage of generation. However, the identification of desirable congestion or eco-technology innovation, in systems that produce undesirable outputs is much more important than that of undesirable congestion from the perspective of environmental assessment. In this paper, we propose an approach to identify desirable congestion that can be effectively used to reduce the amount of undesirable outputs so that systems such as electric power companies satisfy a governmental standard on environmental protection. Thus, the identification of desirable congestion assists us in determining which technology should be invested to facilitate eco-technology innovation and its related engineering management for a future sustainable economic growth. We use the proposed approach to study the pollutants of two empirical data in China and USA

Keywords: Desirable Congestion, Undesirable Congestion, DEA.

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1. Introduction

Congestion is a widely observed phenomenon in which inefficiency is identified in such a manner that an increase in an input decreases an output without worsening the other inputs and outputs [1-3]. Such an occurrence may be found in many economic activities. For example, a petroleum industry has a difficulty in transporting oil and natural gas from their production facilities to consumption areas because a pipeline network among them has a capacity limit on transportation. Another example may be found in a transmission line of electricity that connects between generators and end users. The transmission line has a line limit that determines not only the amount of electricity but also the electricity price in a power trading market. Thus, the phenomenon of congestion can be found in many economic activities [4]. Sueyoshi and Goto [4-5] classified the concept of congestion into "undesirable (bad) congestion" and "desirable (good) congestion". The concept of undesirable congestion indicates a transportation or transmission problem occurring between inputs and desirable outputs. A capacity limit on desirable outputs is not desirable so that this type of congestion is referred to as "undesirable" congestion. The concept of undesirable congestion belongs to a traditional implication of congestion in production economics. In contrast, the concept of desirable congestion indicates a similar phenomenon that occurs between inputs and undesirable outputs. A limit on undesirable outputs is desirable so that this type of congestion is referred to as "desirable" congestion. This type of congestion may usually occur along with technology innovation for environmental protection (e.g., clean coal technology). Chen et.al in [6] extends researches in [4-5] and [7] and proposes the undesirable energy congestion (UEC) and desirable energy congestion (DEC) models.

In this paper, we proposed a new approach to identify desirable congestion (DC). Proposed model has two stages involve solving linear programming and solving linear inequalities. The remainder of this article has the following structure: Section 2 reviews the economic concept of congestion, the concept of natural and managerial disposability. Section 3 documents how to identify an occurrence of desirable congestion. Section 4 applies the proposed approach to assess 31 administrative regions of China and 169 coal-fired power plants in the United States.

2. Preliminaries

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. Färe et al. [8] specified the weak disposability on desirable and undesirable output as follows:

$$p^{W}(X)=\left\{\begin{array}{l}(G,B): G \le \sum_{j=1}^{n} G_j\lambda_j, \\ \qquad B=\sum_{j=1}^{n} B_j\lambda_j,\ X \ge \sum_{j=1}^{n} X_j\lambda_j, \\ \qquad \sum_{j=1}^{n}\lambda_j = 1 \,\&\, \lambda_j \ge 0,\ j=1,2,\dots,n\end{array}\right\} \tag{1}$$

The equality constraints ($B=\sum_{j=1}^{n} B_j\lambda_j$) indicate an occurrence of congestion by weak disposability on undesirable outputs. Färe et al. [8] also specified the strong disposability as follows:

$$p^{S}(X)=\left\{\begin{array}{l}(G,B): G \le \sum_{j=1}^{n} G_j\lambda_j, \\ \qquad B\le\sum_{j=1}^{n} B_j\lambda_j,\ X \ge \sum_{j=1}^{n} X_j\lambda_j, \\ \qquad \sum_{j=1}^{n}\lambda_j = 1 \,\&\, \lambda_j \ge 0,\ j=1,2,\dots,n\end{array}\right\} \tag{2}$$

The inequality constraints ($B \le \sum_{j=1}^{n} B_j \lambda_j$) allow for strong disposability on undesirable outputs.

The economic concept on weak and strong disposability attracted considerable attention among production economists by Sueyoshi and Goto [4-5]. Sueyoshi and Goto [4-5] to extend the concept disposability further introduced two strategic concepts as natural disposability and managerial disposability. The natural disposability indicates that a firm decreases the vector of inputs to decrease the vector of undesirable outputs. Given the decreased vector of undesirable outputs and that of inputs, the firm attempts to increase the vector of desirable outputs as much as possible. For example, let us consider a coal-fired power plant where the CO2 emission is produced by coal combustion. The coal is used as an input for the operation of a coal-fired power plant. If the coal-fired power plant reduces the amount of coal combustion to satisfy a regulation change on undesirable outputs determined by a government or an international agreement, then the reduction immediately decreases the amount of CO2 emission. The coal-fired power plant tries to increase the amount of electricity as much as possible under such regulation. This type of environmental strategy indicates "natural disposability". This concept is originated from the conventional view of production economists. The managerial disposability indicates that a firm increases the vector of inputs to increase the vector of desirable outputs but to simultaneously decrease the vector of undesirable outputs. For example, the coal fired power plant increases the amount of coal combustion to increase the amount of electricity. Here, even if the power plant increases the amount of coal combustion, the increase can reduce the amount of CO2 emission by a managerial effort by using a high quality coal with less CO2 emission and/or an engineering effort to utilize new generation technology (e.g., clean coal technology) that can reduce the amount of CO2 emission. That is a strategic effort for environmental protection. The concept of managerial disposability is used to express regulation enhances technology innovation on undesirable outputs by DEA [4].

The production technology to express natural and managerial disposability is formulated by the following output vectors, respectively [4]:

$$p_v^N(X) = \left\{ \begin{array}{l} (G,B):\ G \le \sum_{j=1}^{n} G_j \lambda_j, \\ \qquad B \ge \sum_{j=1}^{n} B_j \lambda_j,\ X \ge \sum_{j=1}^{n} X_j \lambda_j, \\ \qquad \sum_{j=1}^{n} \lambda_j = 1 \ \&\ \lambda_j \ge 0,\ j = 1,2,\ldots,n \end{array} \right\} \tag{3}$$

$$P_v^M(X) = \left\{ \begin{array}{l} (G,B):\ G \le \sum_{j=1}^{n} G_j \lambda_j, \\ \qquad B \ge \sum_{j=1}^{n} B_j \lambda_j,\ X \le \sum_{j=1}^{n} X_j \lambda_j, \\ \qquad \sum_{j=1}^{n} \lambda_j = 1 \ \&\ \lambda_j \ge 0,\ j = 1,2,\ldots,n \end{array} \right\} \tag{4}$$

$p_v^N(X)$ stands for production and pollution possibility sets that are structured by natural disposability and $p_v^M(X)$ is for those of managerial disposability. The subscript (v) stands for variable return to scale (RTS) and variable damage to scale (DTS) because the side constraint $\sum_{j=1}^{n} \lambda_j = 1$ is incorporated into the two axiomatic expressions [4-5].According the natural disposability and the managerial disposability, Sueyoshi and Goto in [5] introduced the following sets to identify a possible occurrence of UC and DC:

$$p_{UC}^{N}(X)=\left\{\begin{array}{l}(G,B):\ G\le\sum_{j=1}^{n}G_j\lambda_j,\\ \qquad B=\sum_{j=1}^{n}B_j\lambda_j,\ X\ge\sum_{j=1}^{n}X_j\lambda_j,\\ \qquad \sum_{j=1}^{n}\lambda_j=1\ \&\ \lambda_j\ge 0,\ j=1,2,...,n\end{array}\right\} \quad (5)$$

$$P_{DC}^{M}(X)=\left\{\begin{array}{l}(G,B):\ G\le\sum_{j=1}^{n}G_j\lambda_j,\\ \qquad B\ge\sum_{j=1}^{n}B_j\lambda_j,\ X\le\sum_{j=1}^{n}X_j\lambda_j,\\ \qquad \sum_{j=1}^{n}\lambda_j=1\ \&\ \lambda_j\ge 0,\ j=1,2,...,n\end{array}\right\} \quad (6)$$

The set (5) incorporates a possible occurrence of UC under natural disposability. The set (6) one incorporates a possible occurrence of DC under managerial disposability.

Sueyoshi and Goto in [5] visually specified the relationship between a supporting hyperplane on production and pollution possibility sets and the three types of UC and DC: “no”, “weak” and “strong” as Fig 1 and Fig. 2.

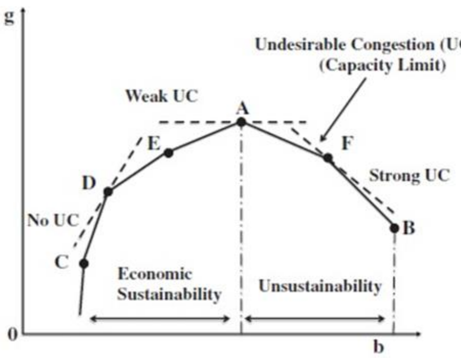

Fig 1. Undesirable congestion

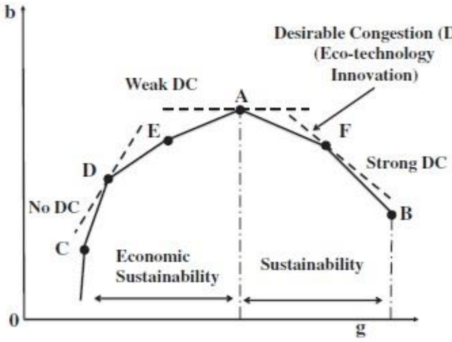

Fig 2. Desirable congestion

The simple case of g and b regarding the two production factors (G and B) is considered in Fig 1 and Fig2. Input is not listed in these figures. The Fig 1 depicts a possible occurrence of UC at the right hand side. Under such an occurrence, an increase in some component(s) of an input vector increases some components of an undesirable output vector (B) and decreases those of an desirable output vector (G)without worsening the other components. The Fig 2 depicts a possible occurrence of DC. Under such an occurrence of DC, as depicted in the right hand side, an increase in some component(s) of an input vector increases some components of a desirable output vector (G) and decreases those of an undesirable output vector (B) without worsening the other components. This type of congestion occurs with eco-technology innovation on undesirable outputs. Using properties of supporting hyperplane, Sueyoshi and Goto in [5] introduced a method to identify DC. In the next section, we propose an approach to recognize DC.

3- Proposed approach

In this section, we suggested an approach to determine the occurrence of desirable congestion. We assume that there are *n* independent and homogenous units, $DMU_j\,(j=1,2,...,n)$,which consume *m* various inputs, $x_{ij}\,(i=1,2,...,m)$, to produce *s* different desirable outputs, $g_{rj}\,(r=1,2,...,s)$ and *k* undesirable outputs $b_{hj}\,(h=1,2,...,k)$. Let DMU_p is DMU under evaluation. The proposed approach has two stages as follows:

Stage 1: solve the following linear programming problem for DMU_p $(p=1,2,...,n)$.

$$
\begin{aligned}
& z_p^* = Max \sum_{h=1}^{k} S_h^b \\
& s.t.\ \sum_{j=1}^{n} \lambda_j x_{ij} \ge x_{ip}, i = 1,2,...,m \\
& \sum_{j=1}^{n} \lambda_j b_{hj} + S_h^b = b_{hp}, h = 1,2,...,k \\
& \sum_{j=1}^{n} \lambda_j g_{rj} \ge g_{rp}, r = 1,2,...,s \qquad (7) \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \lambda_j \ge 0,\ j = 1,2,...,n \\
& S_h^b \ge 0,\ h = 1,2,...,k
\end{aligned}
$$

Define $E^+ = \{ j \mid z_j^* = 0, j = 1,2,...n \}$.

We introduce DMU belonging to E^+ as an efficient DMU in the undesired output-oriented.

Stage 2: solve the following linear inequalities system for $DMU_p\ (p \in \{1,2,...,n\} - E^+)$.

$$
\begin{aligned}
& \sum_{j \in E^+} \lambda_j x_{ij} = x_{ip}, i = 1,2,...,m \\
& \sum_{j \in E^+} \lambda_j b_{hj} \ge b_{hp}, h = 1,2,...,k \\
& \sum_{j \in E^+} \lambda_j g_{rj} = g_{rp}, r = 1,2,...,s \qquad (8) \\
& \sum_{j \in E^+} \lambda_j = 1 \\
& \lambda_j \ge 0,\ j \in E^+
\end{aligned}
$$

According to Fig .2, if (2) has no solution, then "strong DC" occurs on DMU_p.

For example, for DMUs in Fig .2, after solving model (1), we have $E^+ = \{A, E, C, D\}$. In stage 2, model (2) for DMU E and DMU B has no solution. So "strong DC" occurs on them.

4. Numerical example

Example1.In this example, the proposed approach is used on a data set consisting of 31 administrative regions of China, which is selected from [9]. Table 1 indicates these data consist of two inputs: the total investment in fixed assets of industry (TIFA) and the electricity consumption by industry (EC), one desirable output: the gross industrial output value (GIOV), and two undesirable outputs: the total volume of industrial waste gas emission (TWGE) and the total volume of waste water discharge (TWWD).

Results of model (1) and model (2) are shown in last two columns of table 1. From 8th column of table 1, E^+ is as follows:

$$E^+ = \{2,6,10,15,16,18,19,23,24,28\}$$

From the last column in table 1, "strong DC" occurs on the following DMUs:

$$DMU_j\,(j = 1,3,5,7,8,9,11,12,\ 17,20,21,25,26,29,30).$$

Example 2. In this example, the descriptive statistics regarding the data set on 169 coal-fired power plants in 2018 in is shown in Table 2. The data source is the database of Environmental Protection Agency (EPA) "eGRID year 2018" (http://www.epa.gov/energy/egrid).

Table 1: Data set of industry of China in 2010.

Region	DMU	Inputs		Desirable output	Undesirable outputs		Z^* in model (1)	Desirable Congestion
		TIFA	EC	GIOV	TWGE	TWWD		
Anhui	DMU1	9121.829	1077.91	18732	17849	70971	26588.875	Yes
Beijing	DMU2	4554.356	809.9	13699.84	4750	8198	0	
Chongqing	DMU3	5049.258	626.44	9143.55	10943	45180	37834.998	Yes
Fujian	DMU4	6534.803	1315.09	21901.23	13507	124168	89601.025	
Gansu	DMU5	2274.305	804.43	4882.68	6252	15352	8740.5	Yes
Guangdong	DMU6	11903.36	4060.13	85824.64	24092	187031	0	
Guangxi	DMU7	5166.135	993.24	9644.13	14520	165211	154586.97	Yes
Guizhou	DMU8	2483.012	835.38	4206.37	10192	141 30	9820.418	Yes
Hainan	DMU9	903.8264	159.02	1381.25	1360	5782	4248.76	Yes
Hebei	DMU10	11737.07	2691.52	31143.29	56324	114232	0	
Heilongjiang	DMU11	5019.085	747.84	9535.15	10111	38921	31069.565	Yes
Henan	DMU12	12868.24	2353.96	34995.53	22709	150406	22117.296	Yes
Hubei	DMU13	7276.638	1330.44	21623.12	13865	94593	55800.806	
Hunan	DMU14	7374.157	1171.91	19008.83	14673	95605	64934.965	
Inner Mongolia	DMU15	6831.416	1536.83	13406.11	27488	39536	0	
Jiangsu	DMU16	18977.92	3864.37	92056.48	31213	263760	0	
Jiangxi	DMU17	6696.149	700.51	13883.06	9812	72526	45627.078	Yes
Jilin	DMU18	6313.748	576.98	13098.35	8.24	38656	0	
Liaoning	DMU19	12480.94	1715.26	36219.42	26955	71521	0	
Ningxia	DMU20	1193.702	546.77	1924.39	16324	21977	29417.818	Yes
Qinghai	DMU21	789.5051	465.18	1481.99	3952	9031	5360.216	Yes
Shaanxi	DMU22	5462.784	859.22	11199.84	13510	45487	36247.044	
Shandong	DMU23	17664.34	3298.46	83851.4	43837	208257	0	
Shanghai	DMU24	4252.32	1295.87	30114.41	12969	36696	0	
Shanxi	DMU25	4702.091	1460	12471.33	35190	49881	32484.707	Yes
Sichuan	DMU26	9790.274	1549.03	23147.38	20107	93444	37150.012	Yes
Tianjin	DMU27	4571.888	645.74	16751.82	7686	19680	7280.582	
Tibet	DMU28	306.567	20.41	62.22	16	736	0	
Xinjiang	DMU29	2749.838	661.96	5341.9	9310	25413	24060.369	yes
Yunnan	DMU30	4024.972	1004.07	6464.63	10978	30926	17116.949	yes
Zhejiang	DMU31	10246.41	2820.93	51394.2	20434	217426	96388.619	

Table2: Descriptive statistics.

statistics	Input1	Input2	Desirable output	Undesirable output1	Undesirable output2	Undesirable output3
Avg.	1151.254	47428312	4243757	2722.852	3265.012	4145342
Max.	5304	202763269	18325184	12528	30577	18284993
Min.	23	61871	2823	0	0	3301
S.D.	910.042	42764488	3960973	2602.938	4727.998	3781994

Table3: Multiple production factors in power plants.

Input1	Input2	Desirable output	Undesirable output1	Undesirable output2	Undesirable output3
the name plate capacity (MW: Megawatt)	the amount of annual heat input (MMBtu)	the amount of annual net generation (MWh: Megawatt hours)	the annual amount of NOx emissions (tons)	the annual amount of SO2 emissions (tons)	the annual amount of CO2 emissions (tons)

The production factors of each power plant are summarized in the table3.

Among all undesirable outputs, the first two belong to acid rain gases, but not greenhouse gas (GHG). The last one is a GHG. In this study, each observed data is divided by the factor average to avoid the case where a large data set dominates the other small data set in DEA computation. Thus, the data set used in the proposed DEA formulations is structured by index numbers so that they are unit-less. The type of primary fuel of power plants is classified into two categories. One of the two categories is the bituminous (BIT) coal, or called "black coal", that is relatively soft coal that contains a tarlike substance, called "bitumen". The other category is the sub-bituminous (SUB) coal that is a type of coal whose properties range from those of lignite, or called "brown coal", to those of bituminous coal and are used primarily as fuel for steam-electric power generation.

From table 4, E^+ in example2 is as follows:

$$E^+ = \begin{Bmatrix} 1,2,4,5,12,22,23,27,31,44,51, \\ 54,59,70,76,83,126,131,139,161 \end{Bmatrix}$$

From table 4, "strong DC" occurs on the following DMUs:

$$DMU_j \begin{pmatrix} j = 3,10,13,19,24,35,41,45,49,55, \\ 56,62,63,67,71,72,74,75,81,87, \\ 91,96,100,101,106,107,112,113, \\ 114,115,118,120,122,123,124, \\ 125,135,136,137,141,42,143,144, \\ 146,148,150,151,152,154,155, \\ 156,158,159,160,162,163,164, \\ 165,166,167,168,169 \end{pmatrix}$$

5. Conclusion

The identification of UC is important to avoid air pollution gases, a cost increase and a shortage of desirable output in systems that produce undesirable outputs and desirable outputs. In this paper, we used concept managerial disposability to propose an approach involve solving a linear programming problem and inequality system to identify UC.

We used proposed approach to identify UC in 31 administrative regions of China and 169 coal-fired power plants in the United States. Consequently, in 10 industries of 31 administrative regions of China and in 62 power plants in the United States occurred UC. As a result, pollutants in these cases can reduce by increasing inputs and desirable outputs.

Table 4: Results of model (1) and model (2) in example 2

Plant	Plan		DC	Plant	Plan		DC	Plant	Plan		DC	Plant	Plan		DC
1	BIT	0		46	BIT	2.64		91	SUB	0.03	yes	136	SUB	0.51	yes
2	BIT	0		47	BIT	1.64		92	SUB	1.05		137	SUB	0.77	yes
3	BIT	0.03	yes	48	BIT	3.10		93	SUB	4.03		138	SUB	0.95	
4	BIT	0		49	BIT	1.56	yes	94	SUB	3.05		139	SUB	0	
5	BIT	0		50	BIT	3.50		95	SUB	0.31		140	SUB	1.56	
6	BIT	0.08		51	BIT	0		96	SUB	2.12	yes	141	SUB	0.30	yes
7	BIT	0.03		52	BIT	1.24		97	SUB	0.37		142	SUB	0.32	yes
8	BIT	0.27		53	BIT	1.45		98	SUB	1.55		143	SUB	0.28	yes
9	BIT	0.44		54	BIT	0		99	SUB	1.38		144	SUB	4.73	yes
10	BIT	0.06	yes	55	BIT	1.55	yes	100	SUB	0.06	yes	145	SUB	0.67	
11	BIT	0.36		56	BIT	0.80	yes	101	SUB	0.18	yes	146	SUB	0.93	yes
12	BIT	0		57	BIT	1.19		102	SUB	0.22		147	SUB	3.41	
13	BIT	0.71	yes	58	BIT	2.81		103	SUB	2.97		148	SUB	0.23	yes
14	BIT	0.34		59	BIT	0		104	SUB	0.29		149	SUB	2.08	
15	BIT	0.15		60	BIT	1.83		105	SUB	0.41		150	SUB	0.96	yes
16	BIT	0.64		61	BIT	0.58		106	SUB	1.60	yes	151	SUB	0.37	yes
17	BIT	0.49		62	BIT	1.26	yes	107	SUB	1.43	yes	152	SUB	3.53	yes
18	BIT	0.12		63	BIT	0.44	yes	108	SUB	5.36		153	SUB	8.25	
19	BIT	0.39	yes	64	BIT	2.76		109	SUB	1.13		154	SUB	1.43	yes
20	BIT	0.49		65	BIT	3.15		110	SUB	3.27		155	SUB	2.54	yes
21	BIT	0.12		66	BIT	3.15		111	SUB	0.52		156	SUB	0.55	yes
22	BIT	0		67	BIT	1.95	yes	112	SUB	0.36	yes	157	SUB	1.87	
23	BIT	0		68	BIT	3.68		113	SUB	6.24	yes	158	SUB	0.98	yes
24	BIT	0.73	yes	69	BIT	3.25		114	SUB	0.38	yes	159	SUB	1.52	yes
25	BIT	2.81		70	BIT	0		115	SUB	0.78	yes	160	SUB	0.20	yes
26	BIT	0.09		71	BIT	2.77	yes	116	SUB	2.69		161	SUB	0	
27	BIT	0		72	BIT	4.29	yes	117	SUB	1.12		162	SUB	9.54	yes
28	BIT	1.83		73	BIT	1.1		118	SUB	1.33	yes	163	SUB	5.80	yes
29	BIT	0.18		74	BIT	1.54	yes	119	SUB	0.16		164	SUB	9.84	yes
30	BIT	0.88		75	BIT	4.69	yes	120	SUB	0.11	yes	165	SUB	1.49	yes
31	BIT	0		76	SUB	0		121	SUB	0.32		166	SUB	0.13	yes
32	BIT	0.20		77	SUB	0.10		122	SUB	1.12	yes	167	SUB	1.32	yes
33	BIT	0.49		78	SUB	0.52		123	SUB	0.65	yes	168	SUB	0.08	yes
34	BIT	1.35		79	SUB	0.87		124	SUB	0.91	yes	169	SUB	0.3	yes
35	BIT	0.90	yes	80	SUB	0.32		125	SUB	1.03	yes				
36	BIT	2.54		81	SUB	0.48	yes	126	SUB	0					
37	BIT	0.83		82	SUB	0.37		127	SUB	0.84					
38	BIT	1.26		83	SUB	0		128	SUB	4.32					
39	BIT	0.90		84	SUB	1.71		129	SUB	3.20					
40	BIT	1.51		85	SUB	1.08		130	SUB	0.61					
41	BIT	1.41	yes	86	SUB	0.57		131	SUB	0					
42	BIT	0.51		87	SUB	0.08	yes	132	SUB	3.58					
43	BIT	0.90		88	SUB	0.15		133	SUB	7.38					
44	BIT	0		89	SUB	0.3		134	SUB	7.63					
45	BIT	0.52	yes	90	SUB	0.93		135	SUB	2.53	yes				

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