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The Margin Abatement Costs of CO_2 in Chinese industrial sectors

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Abstract

Using the directional distance function estimating by a non-parametric method, this paper measured shadow prices indicating the margin abatement costs (MACs) of CO_2 emissions of China's industrial sectors. The results show that the MACs are within 0.2 thousand Yuan per ton to 120.3 thousand Yuan per ton, differentiating among sectors. In average, the MACs of heavy and chemical industries are lower than that of light and high-tech industries.

Keywords: Carbon dioxide; Marginal Abatement Cost; Directional Distance Function; Shadow Price

1. Introduction

Since reform and opening, along with rapid economic growth, total carbon emissions continue to grow in China. The IEA [1] issued a report that the CO_2 emissions deriving from fossil fuel consumption in China have exceeded the United States. As a big responsible country, reduction of CO_2 emissions is obligatory. However, the implementation will deplete economic resources, to a certain extent, making the economic growth slowing down. Measuring of abatement costs is favour of determining the key industries, thereby reducing the negative impact on the economy.

Pittman [2] and Fare et al [3] were the first to put emissions into the measurement model of productivity and efficiency, and estimated the marginal abatement costs of pollutants. Further, Fare et al [4] measured the shadow prices of pollutants using the output distance function, in order to estimate the marginal abatement costs. Similarly, the input distance function and directional distance function are also used to estimate the shadow price of pollutants [5]. The output and input distance functions have shortcomings of giving the maximum proportional expansion in both good and bad output, while the

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directional distance function more in line with the concept of cleaner production as gives the maximum expansion of good outputs and contraction of bad outputs simultaneously. More recently, Murty et al [6] and Kaneko [7] calculated the margin abatement costs of pollutants by employing the directional distance function.

This paper is organized as followings. Section 2 defines a directional distance function and provides the estimating method of shadow price. Section 3 analyse the measure result, and Section 4 concludes.

2. Methodology

2.1. Directional Distance Function

The directional distance function is the dual of the profit function, having a good economic meaning [5,8].

Let *y* is the vector of desirable (good) outputs, *b* is the vector of undesirable (bad) outputs, *x* is vector of inputs, and then the output possibility set is:

$$P(x) = \{(y,\ b):\ x \text{ can product } (y,\ b)\} \tag{1}$$

P(x) describes all feasible input - output vectors. When inputs are zero, outputs are also zero, which means P (0) = (0, 0). P(x) has the following four properties: First, inputs are free disposability, that is to say if $x' \geq x$, then $P(x') \supseteq P(x)$.Second, the desirable outputs are free disposability, that is to say if $(y, b) \in P(x)$ and $y' \leq y$, then $(y', b) \in P(x)$.This means the good outputs can be freely disposed. Third, the undesirable outputs are weak free disposability, that is to say when θ is within [0, 1], then $(\theta y, \theta b) \in P(x)$.This means the maximum expansion of good outputs and contraction of bad outputs simultaneously is feasible when inputs are given. That also implies there is an opportunity cost of reducing bad inputs. Fourth, good and bad outputs are null-joint. When $(y, b) \in P(x)$ and $y = 0$, then $b = 0$.This means good and bad outputs are jointly produced, unless not produce, the firm cannot produce good outputs without the bad production.

Let $g=(g_y,g_b)$ as the directional vector, and $g \neq 0$.According to these properties, the directional distance function is defined as:

$$\vec{D}_0(x, y, b; g_y, g_b) = \max\left\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\right\} \tag{2}$$

2.2. Non-parametric Estimation Method

The directional distance functions can be estimated by a parametric or a non-parametric estimation method. This paper adopts the parametric approach, because it doesn't impose any priori restrictions on the form of production function. Referring to Kaneko et al [7] and Lee et al. [9], the directional distance function is estimated by linear programming as:

$$\begin{aligned} &\vec{D}_0(x_i, y_i, b_i; y_i, -b_i) = \max_{\beta,\lambda} \beta \\ s.t.\quad &(\text{i}) Y\lambda \geq (1+\beta) y_i; \\ &(\text{ii}) B\lambda \leq (1-\beta) b_i; \\ &(\text{iii}) X\lambda \leq x_i; \\ &(\text{iv}) i^T \lambda \leq 1,\ \ \beta, \lambda \geq 0. \end{aligned} \tag{3}$$

Where X is the input vector, Y and B are vectors of good and bad outputs respectively.

2.3. Derivation of Shadow Price

Undesirable outputs such as pollutants usually don't have market prices, but can be estimated based on relationship between the direction distance and the profits function [10].Let $p=(p_1,...,p_M)$ as the price vector of desirable outputs, $q=(q_1,...,q_J)$ as the price vector of undesirable outputs, $w=(w_1,...,w_N)$ as the price vector of inputs. Then the profit function is defined as:

$$\pi(w,p,q)=\max_{x,y,b}\left\{py-wx-qb:(y,b)\in P(x)\right\} \tag{4}$$

$\pi(w,p,q)$ means the possible maximum profit by a given input. Obviously, the bad outputs have negative impact on the profit function. It implies that abatements of the bad outputs are costly.

As the production unit is always located on or within the production frontier, therefore $\vec{D}_0(x,y,b;g_y,g_b)\geq 0$ .In other words, $(y,b)\in P(x)$ and $\vec{D}_0(x,y,b;g_y,g_b)\geq 0$ are equivalent. It is equivalently to define profit function as:

$$\pi(w,p,q)=\max_{x,y,b}\left\{py-wx-qb:\vec{D}_0(x,y,b;g)\geq 0\right\} \tag{5}$$

If $(y,b)\in P(x)$, then

$$(y+\beta g_y,b-\beta g_b)=\{(y+\vec{D}_0(x,y,b;g)\cdot g_y,b-\vec{D}_0(x,y,b;g)\cdot g_b)\in P(x)\}. \tag{6}$$

Eq. (5) shows that if the output vector (y,b) is feasible, along the direction of g, output is also feasible after eliminating inefficiency. Therefore, the profit function can be written as:

$$\pi(w,p,q)\geq(p,-q)(y+\vec{D}_0(x,y,b;g)\cdot g_y\,,\,b-\vec{D}_0(x,y,b;g)\cdot g_b)-wx \tag{7}$$

Or: $$\pi(w,p,q)\geq(py-wx-qb)+p\vec{D}_0(x,y,b;g)\cdot g_y+q\vec{D}_0(x,y,b;g)\cdot g_b \tag{8}$$

In Eq. (8), the possible maximum profit is on the left and the right is actual profit and additional revenue after eliminating technical inefficiency. This additional revenue consists of two parts: first, the expanded desirable outputs increase income, that is $p\vec{D}_0(x,y,b;g)\cdot g_y$. Second, the reduced undesirable outputs increase benefits, which essentially suggests that due to the reduction of undesirable outputs, the cost of the undesirable outputs deducted from the total income is also decline, that is $q\vec{D}_0(x,y,b;g)\cdot g_b$. If the production unit move to the frontier of production set along the direction vector, the output configuration is efficient. Then the Eq. (8) will become equality.

Eq. (8) can be rewritten as the following:

$$\vec{D}_0(x,y,b;g)\leq\frac{\pi(w,p,q)-(py-wx-qb)}{pg_y+qg_b} \tag{9}$$

Therefore, the direction distance function defined in Eq. (2) can be expressed as:

$$\vec{D}_0(x,y,b;g)=\min_{p,q}\{\frac{\pi(w,p,q)-(py-wx-qb)}{pg_y+qg_b}\} \tag{10}$$

The shadow price model can be got by using envelope theorem on Eq. (10):

$$\frac{\partial\vec{D}_0(x,y,b;g)}{\partial y}=\frac{-p}{pg_y+qg_b}\leq 0 \tag{11}$$

$$\frac{\partial\vec{D}_0(x,y,b;g)}{\partial b}=\frac{q}{pg_y+qg_b}\geq 0 \tag{12}$$

So, if the price of the good output m, p_m, is given, then the price of the bad output j can be calculated by the following formula:

$$q_j = -p_m\left(\frac{\partial \vec{D}_0(x,y,b;g)/\partial b_j}{\partial \vec{D}_0(x,y,b;g)/\partial y_m}\right), \quad j = 1.......J. \tag{13}$$

3. Data and Results

This paper uses input and output data of 24 sectors in China's 29 provinces. Inputs include capital indicated by the average balance of net fixed asset (hundred million), labour indicated by the average number of employees in a year (ten thousand) and energy consumption (ten thousand tons).Outputs include gross industrial output value (hundred million) and carbon dioxide emissions (ten thousand tons, undesirable outputs).The raw data are from the "China Economic Census Yearbook" and "Industry Database", containing two years data, the 2004 and 2008. We combined these two data into a pool of data sets, then each sector obtained 58 (2*29) samples.

Applying the above data, the shadow price of industries can be estimated in all regions. As reduction in carbon dioxide emissions would lead to loss of outputs, so the shadow prices are negative, meaning the mount of total output losses when reduce a unit of carbon dioxide. We calculated the average weighted shadow prices (absolute value) of 24 industries in China and the weight is the share of emissions of an industry in all regions, regarding as marginal abatement cost of the national average in industries. Table 1 shows the results.

The results showed that the MACs vary greatly in different sectors, the heavy and chemical industries mainly have relative lower MACs, such as petroleum processing, coking and nuclear fuel processing industry, mining, electricity, heat, gas and water production and supply industry, chemical materials and products manufacturing and the ferrous metal smelting and rolling processing industry, and the MACs of them are less than 1 thousand Yuan per ton. However, light industry and high-tech industry have relative higher MACs, such as communication equipment, computers and other electronic equipment manufacturing, tobacco industry, plastics industry, special equipment manufacturing and electrical machinery and equipment manufacturing, and the MACs of them are higher than 10 thousand Yuan per ton.

The above results are not difficult to explain, because energy utilization is the essence of carbon dioxide emission. Due to light industry and some high-tech sectors are efficient in energy use, advanced in energy technology and less in energy consumption, the further energy saving would be more costly and difficult. On the contrary, the energy-intensive heavy industries have lower energy efficiency and use a large amount of energy, thus energy saving of them is more potential and less costly. That's why there are various abatement costs in industries.

Table 1. The MACs of CO_2 in industrial sectors (ten thousand Yuan per ton CO_2)

industry	2004	2008	industry	2004	2008
1	0.04	0.04	13	3.35	4.33
2	0.62	0.37	14	0.22	0.25
3	0.91	0.57	15	0.06	0.10
4	1.43	0.41	16	0.67	0.29
5	7.71	6.83	17	1.36	0.96
6	0.53	1.03	18	1.40	1.58

7	0.45	0.54	19	2.01	4.03
8	0.46	0.33	20	2.35	0.65
9	0.06	0.02	21	3.10	2.00
10	0.13	0.04	22	12.03	9.66
11	2.24	0.59	23	0.26	1.08
12	0.57	0.79	24	0.03	0.04

Note: The numbers 1-24 are mining, agro-food processing industry, food manufacturing, beverage, tobacco, textiles and apparel industry, wood processing and wood, bamboo, rattan, palm and grass products industry, paper, printing and stationery manufacturing, petroleum processing, coking and nuclear fuel processing industry, chemical materials and chemical products manufacturing, pharmaceutical manufacturing, rubber products, plastic products industry, non-metallic mineral products industry, smelting and pressing of ferrous metals processing industry, non-ferrous metal smelting and rolling processing industry, fabricated metal products, general equipment manufacturing, equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, communication equipment, computers and other electronic equipment manufacturing, research office equipment and handicrafts manufacturing, electricity, heat, gas and water production and supply industry.

4. Conclusions

This paper uses the shadow price estimation method based on the directional distance function to measure the margin abatement cost of CO_2 in China's industry sector. The results show that the margin abatement costs are quite different in industries. The margin abatement costs of the heavy and chemical industries are lower than that of the light and high-tech industries.

The results imply that, different sectors should be treated differently when formulate national emission reduction policies, can't be treated as the same standard. For those industries with lower abatement costs should be set higher emission reduction targets, and for those higher industries should be set lower targets, so the total cost of reducing emissions should be as small as possible.

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