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MARGINAL ABATEMENT COST CURVE OF CO2 EMISSIONS OF PETROLEUM PROCESSING AND COKING INDUSTRY IN CHINA

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ABSTRACT

Assessing marginal abatement costs (MAC) of emissions can help a firm to mitigate emissions cost-effectively. This study proposes a method to evaluate MAC, which combines strengths of bottom-up engineering methods and top-down economy-wide methods. A parametric directional distance function is employed to estimate MAC from economic perspective, and the abatement level is further incorporated to generate increasing curves, which is similar to the outcomes derived from engineering perspective. This method takes into consideration whether abatement level exceeds abatement potential with current production technologies so as to provide a more realistic estimation of MAC curve. The technique is illustrated through estimating carbon emission marginal abatement cost of petroleum processing and coking industry.

Keywords: abatement potential, abatement target, carbon emissions, directional distance function, marginal abatement cost, shadow price

1. INTRODUCTION

Carbon emissions are usually undesirable outputs in production activities, and the abatement measures of carbon emissions are not cost-free all the time. To fulfill the abatement objectives cost-effectively, assessment of carbon emissions marginal abatement cost (MAC) is vital of important. Most studies use engineering or economic method to estimate MAC. In this paper, we propose a model that incorporates these two methods. The results obtained can be applied to decision making on the choice of abatement levels and help to determine prices of emissions permit, total abatement cost in an emissions trading scheme[1].

2. LITERATURE REVIEW

2.1 MAC estimation from engineering perspectives

The engineering method pays attention to the information on the amount of abatement and the abatement cost for each reduction technology. However, this method ignored other characteristics of mitigation measurements in the estimation.

2.2 MAC estimation from economic perspectives

The economic method employs the data of practical production activities considering the whole production process, and contains the key input and output factors. But it often lacks the information on the relationship between abatement levels and abatement costs. We propose a model that incorporates the MAC of economic method and the abatement levels of engineering method, which focuses on the strengths of each method. And we use the concept of shadow price to denote the MAC derived from economic method.

3. RECONCILED MODEL FOR MAC ESTIMATION

The shadow price is estimated from the directional distance function (DDF). The more details about the DDF and the derivation of shadow price can be found in Fare et al., (2006)[2]. The DDF is illustrated in Figure 1.

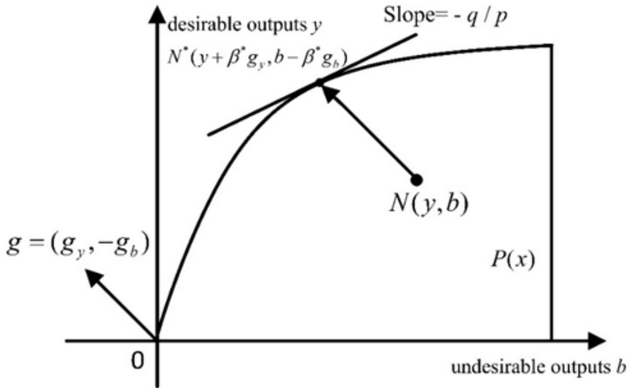

Figure 1 Directional distance function

Following Aigner and Chu (1968)[3], we use linear programming to estimate the unknown parameters in DDF.

$$min\sum_{k=1}^{K}[\vec{D}_0(e_n, y_n e b_n; g_y, g_b) - 0]$$

$$\text{s.t. (i) } \vec{D}_0(x_n, y_n, b_n; g_y, g_b) \geq 0,\ n = 1, \ldots, N;$$

$$\text{(ii) } \frac{\vec{D}_0(x_n, y_n, b_n; g_y, g_b)}{\partial b_u} \geq 0,\ u = 1, \ldots, U,\ n = 1, \ldots, N;$$

$$\text{(iii) } \frac{\partial\vec{D}_0(x_n, y_n, b_n; g_y, g_b)}{\partial y_v} \leq 0, v = 1, \ldots, V, n = 1, \ldots, N;$$

$$\text{(iv) } \frac{\partial\vec{D}_0(x_n, y_n, b_n; g_y, g_b)}{\partial x_i} \geq 0, i = 1, \ldots, I, n = 1, \ldots, N;$$

$$\text{(v) } \sum_{v=1}^{V}\beta_v g_{yv} - \sum_{u=1}^{U}\gamma_u g_{bu} = -1,\ \sum_{v'=1}^{V}\beta_{vv'} g_{yv'} - \sum_{u=1}^{U}\mu_{vu}\, g_{bu} = 0, v = 1, \ldots, V,\ \sum_{u'=1}^{U}\gamma_{uu'} g_{bu'} - \sum_{v=1}^{V}\mu_{vu}\, g_{yv} = 0, u = 1, \ldots, U,\ \sum_{v=1}^{V}\delta_{iv}\, g_{yv} - \sum_{u=1}^{U}\eta_{iu}\, g_{bu} = 0, i = 1, \ldots, I;$$

$$\text{(vi) } \alpha_{ii'} = \alpha_{i'i}, i \neq i', \beta_{vv'} = \beta_{v'v}, v \neq v', \gamma_{uu'} = \gamma_{u'u}, u \neq u' \qquad (1)$$

The model we propose can reflect the changing pattern of shadow price in Figure 2, and the derivation of shadow price can be obtained in two different situations:

(i) The amount of CO_2 abatement is less than the CO_2 abatement potential. The point A and A_1 in Figure 2 can illustrate this situation. If a production unit has r% reduction target, the shadow price is estimated as:

$$q_u = -p_v \cdot \left(\frac{\partial\vec{D}_0(x, y, b(1-\mathrm{r}\%); g)}{\partial b(1-\mathrm{r}\%)} / \frac{\partial\vec{D}_0(x, y, b(1-\mathrm{r}\%); g)}{\partial y}\right) \qquad (2)$$

(ii) The amount of CO_2 abatement is larger than or equal to the CO2 abatement potential. The mitigation target of A_3 cannot be satisfied with current technology level, then, the desirable outputs need to be contracted through shifting along the production frontier. Since the point achieving the target is on the boundary, we can express the function of this point as follows, where y' is the adjusted desirable output:

$$\vec{D}_0 = (x, y', b(1-\tau\%); g_y, g_b) = 0 \qquad (3)$$

Since the parameters of the production function have been estimated through Model (1), and $b(1-\tau\%)$ is known, the DDF can be rewritten as:

$$\frac{1}{2}\beta_{11}y'^2 + (\beta_1 + \sum_{i=1}^{I}\delta_i x_i + \mu_{11}b(1-\tau\%))y' + \alpha + \sum_{i=1}^{I}\alpha_i x_i + \frac{1}{2}\sum_{i=1}^{I}\sum_{i'=1}^{I}\alpha_{ii'}x_i x_{i'} + \frac{1}{2}\gamma_{11}b(1-\tau\%)b(1-\tau\%) + \sum_{i=1}^{I}\eta_i x_i b(1-\tau\%) + \gamma_1 b(1-\tau\%) = 0 \qquad (4)$$

We can obtain y' by solving Equation (4), and the shadow price can be derived from:

$$q_u = -p_v \cdot \left(\frac{\partial\vec{D}_0(x, y', b(1-\mathrm{r}\%); g)}{\partial b(1-\mathrm{r}\%)} / \frac{\partial\vec{D}_0(x, y', b(1-\mathrm{r}\%); g)}{\partial y'}\right) \qquad (5)$$

Since a production unit may choose different CO2 reduction measures, we estimate the average value of shadow price derived from the directional vectors between g = (1, 0) and (1, –1) (as shown in Figure 3) to provide a more representative estimation.

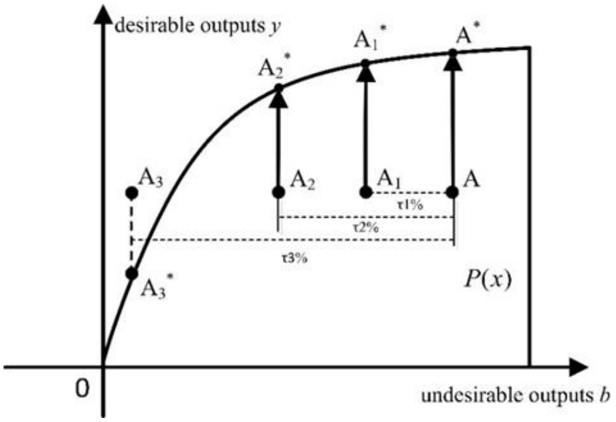

Figure 2 Illustration of abatement level change

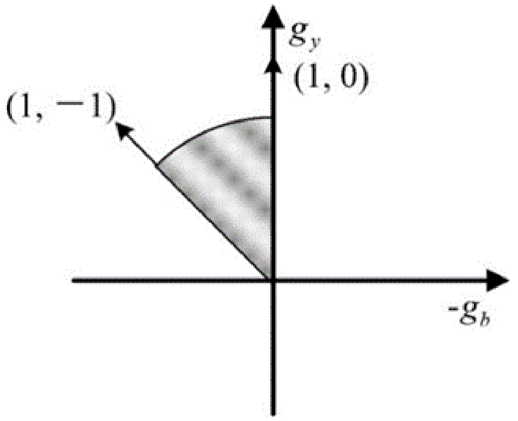

Figure 3 Range of directional vectors

4. APPLICATION OF RECONCILED MODEL

To demonstrate the proposed model, we employ the provincial data of the petroleum processing and coking (PPC) industry in China during 2011 and 2015.

4.1 MAC curves

Figure 4 depicts the pattern of average MAC of PPC industry of 30 provinces, which shows an increasing tendency as the abatement level increases. The MAC associated with 45%~50% abatement levels show sharply increasing patterns indicating that further carbon emission reduction will cost a lot if production units have released the CO2 abatement potential sufficiently.

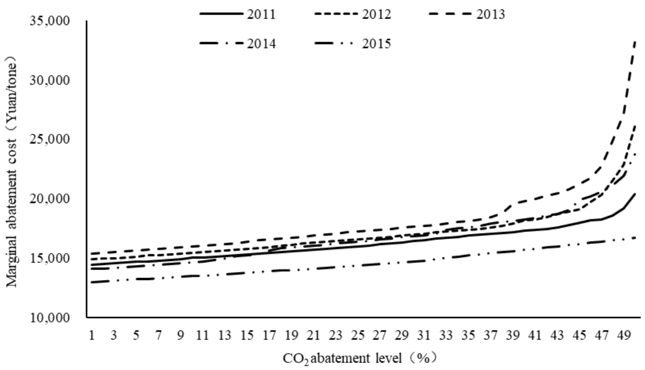

Figure 4 Marginal abatement cost curves of petroleum processing and coking industry (average of 30 provinces)

4.2 MAC under specific reduction target

We select three representative concentration pathways (RCPs) to evaluate the relationship between the MAC and the reduction target, which are RCP2.6, RCP4.5, and RCP6.0. The business-as-usual (BAU) scenario considered is the current carbon emission level. The relationship between the MAC and the amount of carbon emission abatement among thirty provinces under different scenarios is illustrated in Figure 5. From the Figure 5, the RCP 6.0 scenario is under greater pressure for CO2 abatement than the other scenarios. In addition, the higher reduction target for a province usually corresponds to the lower MAC. Figure 6 additional illustrate the relationship between the MAC and the abatement levels in a different form. The meaning of abbreviations in Figure 6 is presented in Table 1. What can be seen from Figure 6 is the ranks of the MAC for a specific province may vary under three low carbon scenarios.

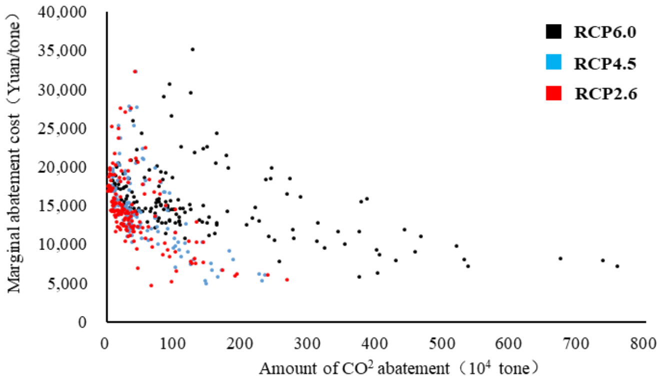

Figure 5 Relationship between marginal abatement cost and amount of CO2 abatement (30 provinces during 2011~2015)

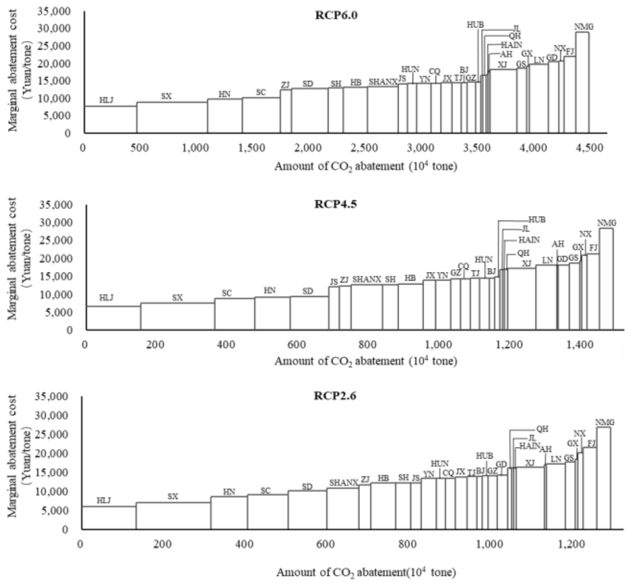

Figure 6 Rank of marginal abatement cost associated with amount of CO₂ abatement across 30 provinces (average value of 2011~2015)

Table 1 The meaning of abbreviations

Abbreviation	Meaning	Abbreviation	Meaning
BJ	Beijing	HN	Henan
TJ	Tianjin	HUB	Hubei
HB	Hebei	HUN	Hunan
SX	Shanxi	GD	Guangdong
NMG	Inner Mongolia	GX	Guangxi
LN	Liaoning	HAIN	Hainan
JL	Jilin	CQ	Chongqing
HLJ	Heilongjiang	SC	Sichuan
SH	Shanghai	GZ	Guizhou
JS	Jiangsu	YN	Yunnan
ZJ	Zhejiang	SHANX	Shaanxi
AH	Anhui	GS	Gansu
FJ	Fujian	QH	Qinghai
JX	Jiangxi	NX	Ningxia
SD	Shandong	XJ	Xinjiang

5. CONCLUSIONS

This paper makes a marginal contribution to the technique for estimating MAC curve by reconciling the engineering and economic methods, and investigating the relationship between the MAC and the emission reduction targets. The illustrating results imply that: (i) as carbon emission reduction target increases, the MAC will grow with an increasing rate; (ii) the provinces with larger potentials on carbon emission abatement usually have lower MAC; (iii) the sensitivity of carbon emission abatement costs to carbon emission reduction targets varies significantly among provinces.

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