

THE CARBON DIOXIDE MARGINAL ABATEMENT COST CALCULATION OF CHINESE PROVINCES -BASED ON STOCHASTIC FRONTIER ANALYSIS

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Abstract: Chinese government made a commitment to achieve a 40%-45% reduction in carbon emissions per unit of GDP by 2020 compared with 2005. Lacking central government's differentiation carbon dioxide reduction allocation, most provinces follow the national commitment. However, the different industrial structures, energy consumption structures and natural resources of each Chinese province made the emission abatement costs varied. Each province should take carbon dioxide abatement cost into consideration of carbon dioxide reduction target. Data envelopment analysis and linear programming methods were used to measure marginal abatement cost from previous studies. To overcome the flaw of ignoring random error and approximation error which was brought by selecting function forms, this paper build a quadratic parametric directional distance function combine with stochastic frontier analysis method to measure the carbon dioxide marginal abatement cost of Chinese provinces. The result shows that the average carbon dioxide marginal abatement cost of each province is 46% lower than previous studies. Besides, the carbon dioxide emissions and marginal abatement cost of each province varied. Meanwhile, there is no distinct correlation between carbon dioxide emissions and the marginal abatement cost. On the other hand, the marginal abatement cost was related to industrial structures, energy consumption structures and natural resources of each province. Therefore, two policy suggestions were proposed. First, overall energy production and consumption structure in China should be changed. Secondly, synergetic development in industry structure and economy should be promoted among provinces.

Key words: carbon dioxide, marginal abatement cost, directional distance function, stochastic frontier analysis, policy suggestions

1. Introduction

The rapid development of Chinese economy has caused a large amount of carbon dioxide (CO₂) emission. CO₂ emission of China has increased quickly since 2000 (Song, 2010; Guo et al., 2010), as the proportion of Chinese CO₂ emission in the global emission has increased from 12.9% in 2000 to about 23% in 2010 (China Electricity Council, 2011). Besides, the proportion has sharply reached quintile in 2013 (Nyakundi et al., 2013). According to a scientific forecast, the proportion will

drastically increase to one-third if no effective CO₂ emission restriction has imposed in China (Liao & Wei, 2011). Facing both the awareness of environmental protection and the international pressure on CO₂ emission reduction, Chinese government made a commitment that achieving a 40%-45% reduction in carbon emissions per unit of GDP by 2020 compared with 2005 in the Climate Conference in Copenhagen in 2009(China.com, 2009). Lacking central government's differentiation carbon dioxide reduction allocation, most provinces follow the national commitment. However, the industrial structure, energy consumption structure and natural resources of each province vary. Hence, it's not appropriate that all provinces¹ impose the identical CO₂ emission reduction criterion. To address this issue, previous studies researches on CO₂ emission abatement cost of China as whole and individual Chinese provinces. Policy suggestions are also proposed by these studies.

The related studies about Chinese CO₂ abatement cost can be divided into two aspects: the marginal abatement cost (MAC) and macro abatement cost (Wang, 2007; Fan et al., 2010; Xu & Dong, 2011; Chang, 2014). CO₂ MAC, also called CO₂ shadow price, is defined as the decrement amount of GDP when reduce the last unit of CO₂ emission in a certain abatement technology status (Fan, 2011; Chen, 2010; Matsushita & Yamane, 2012). CO₂ macro abatement cost is defined as the decrement of GDP when imposing CO₂ emission reduction measures in a certain period (Wang et al., 2007, Fan et al., 2010, Xu & Dong, 2011). The MAC can express the complexity of CO₂ reduction more directly than macro abatement cost.

Directional Distance Function (DDF) has been widely used by previous studies in calculation of CO₂ MAC. However, the different forms of DDF model will lead to different calculation results. In addition, the two methods commonly used by previous studies to solve DDF, data envelopment analysis (DEA) and linear programming (LP), also have flaws. Differentiable everywhere of function are required while using DEA method. Besides, different frontier of production function and direction vector of DEA method will lead to different CO₂ MAC results. LP method doesn't take measuring error and approximation error in to consideration. Therefore, the calculated results of CO₂ reduction cost varied in previous studies.

DDF followed by stochastic frontier analysis (SFA) method can eliminate random error thereby is used to count accurate CO₂ MAC of Chinese provinces in this paper. The result shows that the average carbon dioxide marginal abatement cost of each province is 46% lower than previous studies. Accordingly policy suggestions considering each Chinese province's disparity of CO₂ MAC, industrial structure, energy consumption structure and natural resources are proposed.

This paper is organized as follows. Section 2 introduces the literature review of carbon dioxide abatement cost. Section 3 describes the model and method. Section 4 constructs the direction distance model and stochastic frontier analysis. The conclusion and policy suggestions in section 5.

2. Literature Review

The existing studies show that a multitude of quantitative models are used to measure

¹ Beijing, Tianjin, Shanghai and Chongqing are municipalities

the CO₂ MAC.

2.1 Distance Function

The existing studies show that distance function model, especially parametric DDF model, is the most widely used model in CO₂ MAC. Shephard output distance function was used by Lee, Rezek and Campbell separately to measure the American power station's MAC of sulfur dioxide, nitrogen dioxide, carbon dioxide and mercury (Lee, 2005; Rezek& Campbell, 2007). Hailu and Veeman then used Shephard output distance function to measure the Canadian paper industry's sulfur dioxide MAC (Hailu& Veeman, 2000). Wang and Wei used Output distance function to measure CO₂ MAC of energy sectors of 30 Chinese provinces (Wang & Wei, 2014b).

DDF was applied in many fields of MAC. Färe measured MAC of sulfur dioxide and carbon dioxide of 209 American power facilities (Färe, 2005). Matsushita and Yamane measured CO₂ and low-level radioactive waste MAC of Japanese electric power sector (Matsushita & Yamane, 2012). Gómez-Calvet et al. measured the MAC of undesirable output in 25 European countries (Gómez-Calvet et al., 2014). Wang et al. measured MAC of total nitrogen, total phosphorus and chemical oxygen demand in Chinese agriculture industry (Wang et al., 2014a). In addition, using DDF, previous studies measured CO₂ MAC of industrial sectors of China and Chinese provinces (Chen, 2010; Qin et al., 2011; Wen & Wu, 2011; Wang et al., 2011a; Yuan et al., 2012; Chen, 2013; Zhou et al., 2015).

Specifically, CO₂ MAC of Chinese provinces have been calculated by previous studies. Wang et al. measured CO₂ MAC of 28 provinces in 2007 by nonparametric DDF and DEA methods (Wang et al., 2011b). Liu et al. measured CO₂ MAC of 30 provinces from 2005 to 2007 by nonparametric DF and DEA methods (Liu et al., 2011). Huang and Wei measured CO₂ MAC of 29 provinces from 1995 to 2007 by DDF and LP methods (Huang & Wei, 2012). Zhang et al. measured CO₂ MAC of 30 provinces from 2006 to 2010 by DDF and LP methods (Zhang et al., 2014). He measured CO₂ MAC of 29 provinces from 2000 to 2009 by DF and LP methods (He, 2015). Due to the different methods and samples, the CO₂ MAC results varied. These are shown in Table 1.

Table 1 Comparison of estimated CO₂ MAC of Chinese provinces

Studies	Method	Sample	MAC
Wang et al.	DDF/DEA	28 provinces, 2007	475yuan/ton
Liu et al.	DF/DEA	30 provinces, 2005-2007	1739yuan/ton
Huang & Wei	DDF/LP	29 provinces, 1995-2007	1128yuan/ton
Zhang et al.	DDF/LP	29 provinces, 2006-2010	80.19yuan/ton
He	DF/LP	29 provinces, 2000-2009	104yuan/ton

2.2 Other models

Marginal cost curve model, Vector Auto-Regression (VAR) model and MARKAL model are commonly used in CO₂ MAC calculation. Marginal cost curve model was used by Li et al., Grag et al. and Wang et al. to measure CO₂ MAC of China as a whole, India as a whole and Chinese energy sector (Li et al., 2010; Grag et al., 2014; Wang et al., 2014c). Ba and Wu, Xu and Lin used VAR model to measure CO₂ MAC

of China as a whole and Chinese transportation sector (Ba & Wu, 2010; Xu & Lin, 2015). MARKAL and MARKAL-MACRO model was used to measure CO₂ MAC of China and Taiwan's energy sector (Gao, 2004; Chen, 2005; Chen et al. 2007; Ko et al., 2010).

2.3 Comments on Literature

All above-mentioned models have room for improvement. Although the marginal cost curve model is simple in computation, the form of cost curve will lead to fitting error. GDP was treated as input in VAR model and MARKAL model while distance function model consider GDP as output. Thereby, GDP and CO₂ emission can be treated equally in distance function model. Therefore, distance function model is more suitable as MAC have close relationship with economic loss.

Parametric distance function and nonparametric distance function were two popular methods used to measure CO₂ MAC (Liu et al., 2011). Parametric distance function needs to pre-establish a function which is differentiable everywhere while specific function is not needed in nonparametric distance function. The parametric distance function has the advantage of manipulate algebraically (Choi et al., 2012). In 1990s, Shephard output distance function was first used to measure the MAC of pollutants (Shephard, 1970). The desirable and undesirable outputs are changed in same ratio in Shephard output distance function (Tu, 2009; Dou & Li, 2012; Chen, 2011). In the reality, however, we want to increase desirable output while decrease undesirable output. The DDF which was proposed by Chambers and Färe can achieve reality requires (Chambers et al., 1996; Färe, 1993).

DEA and LP methods are usually used to solve distance function. However, DEA method can only be applied when the function is differentiable everywhere. Besides, different production frontiers and directional vectors will lead to calculated result variation (Lee et al., 2002; Vardanyan & Noh, 2006). Although the LP method can guarantee differentiable everywhere of function, statistic noise will affect the results prominently when there exist particular points was ignore in LP method (Zhang & Choi, 2014; Zhou et al., 2010). Hence, both DEA and LP methods have flaws.

To measure MAC more precisely, DDF and SFA were used by this paper to overcome DEA and LP defect. Besides, SFA has translation property which can consider influence of statistical noise on model (Du & Mao, 2015).

3. Model And Method

DDF model measuring MAC of undesirable output was proposed by Chambers and Färe separately. DDF depicts an input-output process with multiple input and outputs based on production function. Then a production possibility curve (PPC) in the two-dimensional space was built. However, PPC boundary optimal cannot be touched as the restriction of technology. Hence, MAC can be measured by distance between output set and PPC boundary.

3.1 Establishment of DDF

In a certain Chinese province, consider a production process employs three inputs

capital (X_k), labor (X_L) and energy (X_E) and one desirable output GDP (y) and one undesirable output CO₂ emission (b). The production technology set P can be defined as:

$$P = \{(y,b): X \text{ can produce } (y,b)\}$$

The set has following properties:

(1) Inputs are free disposability: The increase of inputs will lead to increased output, that is to say, if $x' \geq x$, then $P(x') \supseteq P(x)$.

(2) Undesirable outputs are weak free disposability: Proportionate reduction of desirable and undesirable outputs simultaneously is possible with given inputs, in other words, $(y,b) \in P, 0 \leq \theta \leq 1$, then $(\theta y, \theta b) \in P$.

(3) Desirable outputs are free disposability: Desirable output reduction is possible with given inputs and undesirable output, so, $(y,b) \in P, y' \leq y$, then $(y', b) \in P$.

(4) Null-jointness: desirable output must be accompanied by the generation of undesirable and the only way to avoid desirable and undesirable outputs is to stop all production activities which means $(y,b) \in P$, and $b=0$, then $y=0$.

Let $g=(g_y, g_b)$ as the directional vector which indicates the expansion of GDP in the direction of g_y and the reduction of CO₂ in the direction of g_b , then the DDF can be defined as:

$$\bar{D}(X, y, b; g) = \sup\{\beta : (y + \beta g_y, b - \beta g_b) \in P\} \quad (1)$$

β presents the maximum proportion of expansion or reduction. $\beta=0$ when the decision making unit lies on the production frontier.

Fig. 1 is the schematic diagram of DDF and the MAC of CO₂ emission.

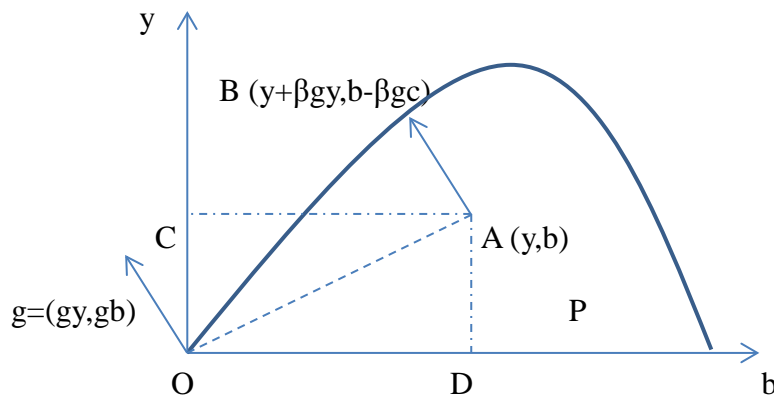


Fig.1 Directional Distance Function

Point A stands for a certain region in the production technology set P , while coordinate axis y and b represent GDP and CO₂ emission in this region respectively. A moves toward point B, which not only reduces undesirable output (CO₂ emission) but also increase desirable output (GDP). Hence, DDF is measured by $\beta=AB/Og$.

3.2 Calculation of DDF

Translog and quadratic form of function are used to calculate DDF. Translog form of function depicts a proportionate at transformation of desirable and undesirable output

simultaneously. Quadratic form of function, on the other hand, depicts a transformation of increasing of desirable output while decreasing of undesirable at the same time (Wei et al., 2013). Hence, quadratic form is suitable for reality.

$$\begin{aligned} \bar{D}(x, y, b; g_y, -g_b) = \\ \alpha_0 + \sum_{i=K,L,E} \alpha_i x_i + \alpha_y y + \alpha_b b + \frac{1}{2} \sum_{i=K,L,E} \sum_{j=K,L,E} \alpha_{ij} x_i x_j + \frac{1}{2} \alpha_{yy} y^2 + \frac{1}{2} \alpha_{bb} b^2 + \sum_{i=K,L,E} \alpha_{iy} x_i y + \sum_{i=K,L,E} \alpha_{ib} x_i b + \alpha_{yb} y b \end{aligned} \quad (2)$$

subject to

$$\begin{aligned} g_y \beta_y - g_b \gamma_b &= -1; \\ g_y \beta_{yy} - g_b \mu_{yb} &= 0; \\ g_y \mu_{yb} - g_b \gamma_{bb} &= 0; \\ g_y \sum_{i=K,L,E} \delta_i - g_b \sum_{i=K,L,E} \eta_i &= 0; \\ g_y^2 \beta_{yy} + g_b^2 \gamma_{bb} - g_y g_b \mu_{yb} &= 0; \end{aligned} \quad (3)$$

DEA and LP methods are usually used in solving DDF. However, production function form will distinct affect results (Zhou et al., 2014). Hence, SFA method which can manage random error is used to solve DDF in this paper.

SFA method was proposed by Aigner et al. (Aigner et al., 1977). Färe et al. applied SFA to DDF (Färe et al., 2005).

$$\bar{D}_0(x^n, y^n, b^n; g_y, -g_b) + v^n - u^n = 0 \quad (4)$$

v represents noise and satisfies normal distribution, i.e., $v^n \sim N(0, \sigma_v^2)$, u represents

random error and satisfies half-normal distribution, i.e., $u^n \sim N^+(0, \sigma_u^2)$.

The revenue of a certain region can be defined as:

$$R = p[y + (1 - \bar{D}_0)g_y] - p_b[b - (1 - \bar{D}_0)g_b] \quad (5)$$

p represents price of GDP. Let $p=1$. p_b represents price of CO₂ and indicate MAC in this paper.

MAC express by Eq. 6 after taking partial derivation of b and y on Eq. 5.

$$p_b = \frac{\partial \bar{D}_0}{\partial b} \times \frac{\partial y}{\partial \bar{D}_0} \quad (6)$$

Eq.2 is the first-order homogeneous equation which contains desirable and undesirable outputs. To measure MAC, natural logarithm was taken as normalization process on Eq.2.

$$\ln D_0 = \ln(D_0 / y) = \ln D_0 - \ln y \quad (7)$$

Hence,

$$\begin{aligned}
-\ln y = & \alpha_0 + \alpha_k \ln x_k + \alpha_l \ln x_l + \alpha_e \ln x_e + \gamma_b \ln b + \frac{1}{2} \alpha_{kl} \ln x_k \ln x_l + \frac{1}{2} \alpha_{le} \ln x_l \ln x_e \\
& + \frac{1}{2} \alpha_{ke} \ln x_k \ln x_e + \frac{1}{2} \gamma_{bb} (\ln b)^2 + \eta_k \ln x_k \ln b + \eta_l \ln x_l \ln b + \eta_e \ln x_e \ln b - \ln D_0
\end{aligned} \tag{8}$$

$0 < D_0 < 1$, then $\ln D_0 < 0$.

According to Eq. 3 and numerical value of inputs and outputs, MAC can be expressed as:

$$\begin{aligned}
p_b = & -\frac{y}{b} \left(\frac{\partial \ln D_0}{\partial \ln b} / \frac{\partial \ln D_0}{\partial \ln y} \right) \\
= & -\frac{y}{b} (\gamma_b + \gamma_{bb} \ln b + \eta_k \ln x_k + \eta_l \ln x_l + \eta_e \ln x_e)
\end{aligned} \tag{9}$$

3.3 Data

3.3.1 Data Resources

Inputs in this paper include capital, labor and energy. Perpetual inventory method which proposed by Goldsmith in 1951 is generally accepted by previous studies to measure capital stock. In measurement of Chinese capital stock, perpetual inventory method is widely used (Zhang et al., 2004; Shan, 2008; Xiang & Ye, 2011; Fan, 2012). Labor and GDP are derived from the *2013 China Statistic Yearbook* and energy consumption is derived from the *2013 China Energy Statistic Yearbook*. Besides, energy consumptions are estimated as standard coal by considering standard coal coefficient. CO₂ emission is measured by the IPCC method.

3.3.2 Measurement of CO₂ emission

CO₂ emission coefficient method is the most commonly method to measure CO₂ emission. According IPCC 4th Climate Change Assessment Report, 90% of CO₂ emission came from combustion of fossil fuels in developed country. Fossil fuels are the main energy resource in undeveloped countries like China. Therefore, the CO₂ emission from fossil fuel accounts more than 90% in China (Diakoulaki & Mandaraka, 2007).

Due to the specific application of energy resources from the *China Energy Statistic Yearbook*, seven energy, Coal, Coke, kerosene, gasoline, fuel oil, diesel and natural gas were chosen to measure CO₂ emission. Most crude oil is used to produce fuel oil and gasoline. Hence, crude oil is not taking into account.

According to *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), the CO₂ emission can be calculated by Eq. 10.

$$C_i = E_{ij} \times \delta_j \tag{10}$$

C_i presents CO₂ emission of province i . E_{ij} presents consumption of energy j in province i . δ_j presents coefficient of CO₂ emissions of energy j .

Emission factors of energy resources were discussed by previous studies (Xu et al., 2006; Wang & Zhu, 2008). The U.S. Department of Energy Information

Administration, the Chinese Academy of Engineering, Sustainable development strategy research group of the Chinese Academy of Sciences, Energy Research Institute of the National Development and Reform Commission and Institute of Policy and Management of the Chinese Academy of Sciences all measure the emission factors of energy. However, the different variety of energy and carbon content of energy caused results varied.

The Measurement of CO₂ emission factor IPCC proposed is showed by Eq.11.

$$\delta_j = M_j \times \beta_j \times \varepsilon_j \times \omega \quad (11)$$

M_j presents net calorific value of energy j . β_j presents carbon content of the unit heat value of energy j . ε_j presents carbohydrate oxidation of energy j . ω presents gasification coefficient of CO₂ and has constant value of 44/12. According to standard coal coefficient, net calorific power, carbon content and oxygenation efficiency in *2014 China Energy Statistic Yearbook* and Eq. 11, CO₂ emission factors are measured in Table 2.

Table 2 CO₂ emission factors of energy

Energy	CO ₂ emission factor	Energy	CO ₂ emission factor
Coal	2.3816	Fuel Oil	3.1704
Coke	2.8526	Diesel Oil	3.0959
Kerosene	3.0333	Natural Gas	2.1650
Gasoline	2.9250		

Put energy consumption data and CO₂ emission factors of each energy into Eq.10, CO₂ emission of Chinese provinces can be calculated.

3.3 Measurement of CO₂ MAC

Put CO₂ emission values into Eq.9 and use Frontier4.1 software, was used to calculate DDF's coefficient.

Table 3 DDF's coefficient

Coefficient	Value	Coefficient	Value
r_b	-0.038	η_l	-0.019
r_{bb}	0.068	η_e	0.008
η_k	-0.031		

CO₂ MAC of Chinese provinces can be measured by Eq.9.

4. Results and Discussion

4.1 Results

4.1.1 CO₂ emission

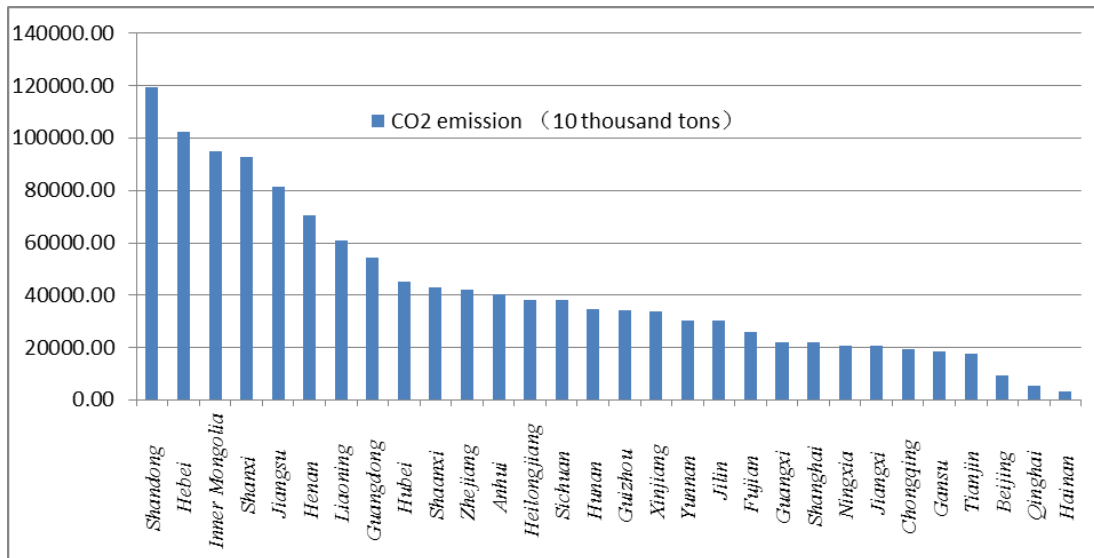


Fig. 2 CO₂ emission of Chinese provinces in 2012 (units: 10 thousand tons)

According to Figure 2, CO₂ emissions of Chinese provinces differ drastically. Large CO₂ emitters like Shandong province, Hebei province and Inner Mongolia Autonomous Region are provinces with flourishing industry. Small CO₂ emitters can be classified into two groups. Beijing City and Tianjin City have small territory and well-developed tertiary industry. Provinces lies in west and south China like Ningxia Hui Autonomous Region, Gansu province and Qinghai province are also the small emitter.

4.1.2 MAC

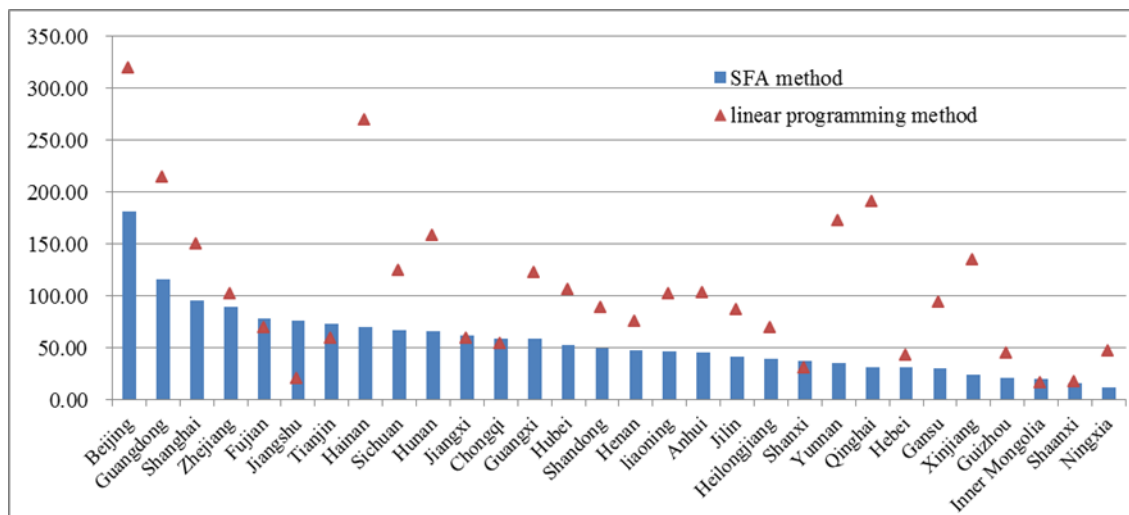


Fig. 3 CO₂ MAC of Chinese provinces in 2012 using SFA and LP method (units: yuan/ton)

According to Figure 3, MAC of Chinese provinces differ exceedingly. The calculation result of SFA method is as follow: Eastern provinces like Beijing and Shanghai have high MAC while Western and Southern provinces like Guizhou, Gansu have low MAC. Provinces with affluent industry like Shanxi and Inner Mongolia Autonomous Region are also have low MAC. Using LP method, the results have slightly

differences. Beijing, Hainan, Guangdong, Shanghai, Hunan, Yunnan and Qinghai have high MAC while Jiangsu, Shanxi, Inner Mongolia and Shaanxi have low MAC. The average result of MAC calculated by SFA method is 46% lower than LP method.

4.2 Discussion

4.2.1 Reliability Test of the MAC Result

Frontier4.1 software was used to measure coefficient of DDF. The result shows that $\gamma^2 = \sigma_u^2 / \sigma^2 = 0.5$. The result of r presents half of error was caused by random error.

Hence, SFA method is necessarily used in this paper.

Meanwhile, coefficient of Eq.9, standard deviation and statistical tests at 1% significance were shown in Table 4.

Table 4 Coefficient of DDF, standard deviation and t ratio

coefficient	coefficient value	standard deviation	T ratio
r_b	-0.038	2.682	-1.825
r_{bb}	0.068	2.041	3.376
η_k	-0.031	1.374	-2.319
η_l	-0.019	1.298	-1.923
η_e	0.008	1.147	-7.082

Referring to the critical value table of t-test, the critical value of 19 degree of freedom is 1.729. The absolute value of t ratio value in Table 4 is greater than the critical value which means the t-test of coefficient is significant and the coefficient result is reliable.

4.2.2 Influence factor analysis of MAC

The composition of CO₂ emission and comparison between CO₂ emission and MAC are shown in Fig.4 and Fig. 5.

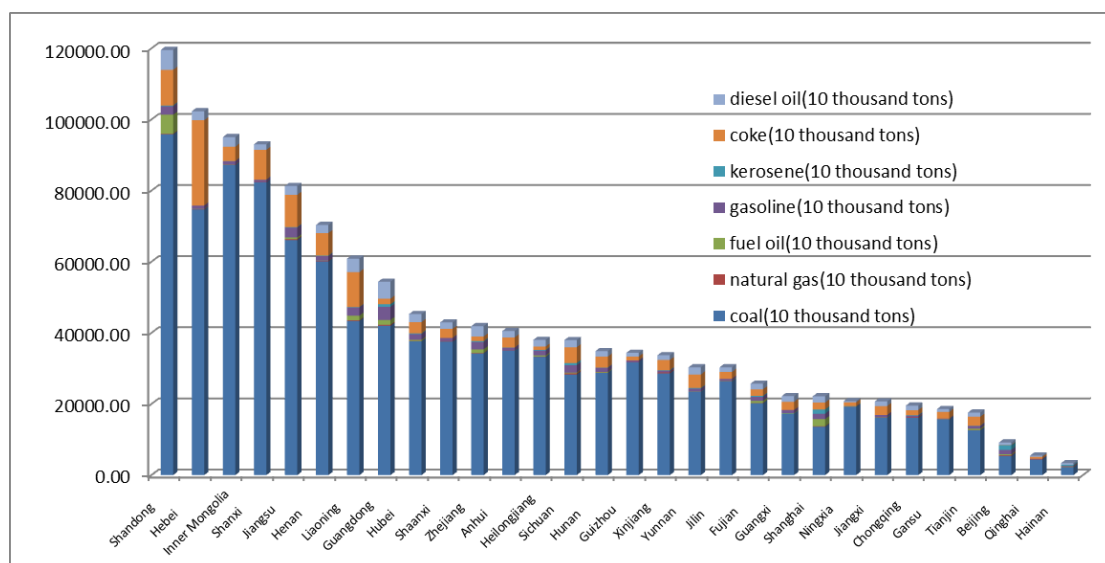


Fig.4 CO₂ emission of Chinese provinces in 2012

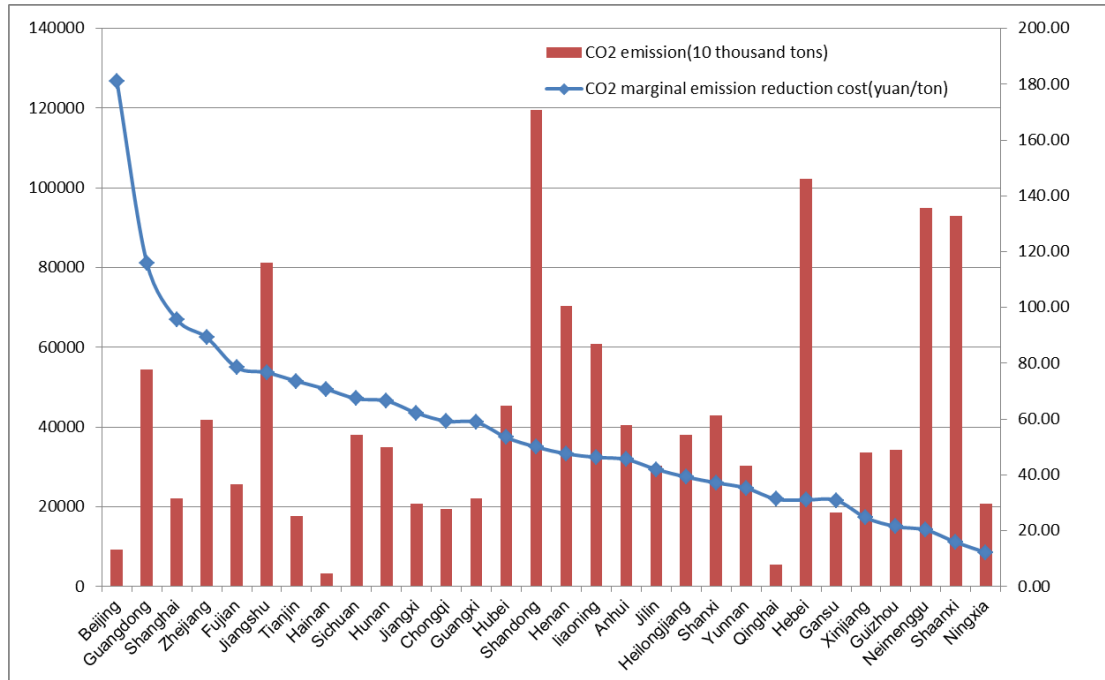


Fig.5 Comparison between CO₂ emission and MAC of Chinese provinces

In general, there are no distinct correlation between CO₂ emission and MAC of Chinese provinces. Industrial structures, energy consumption structures and natural resources are the factors have influence on CO₂ emission and MAC of Chinese provinces.

(1) Industrial structures

Fig.4 shows that large CO₂ emitters like Shandong, Hebei, Shanxi and Inner Mongolia are highly-developed industry provinces. According to *2014 China Statistic Yearbook*, the ratios of secondary industry of large emitters are more than 50%. Especially, high-carbon secondary industry like steel industry and mining industry are the leading industry in those large emitters. Hence, the MACs of large emitters are low. Small emitters can be divided into two groups. First group is provinces with highly-developed but low-carbon tertiary industry like financial industry wholesale and retail trade industry and catering accommodation industry. Beijing, Tianjin, Shanghai and Hainan are in the first group. The ratios of low-carbon industry in those provinces are more than half of total ratio of tertiary industry. As low-carbon industries emit little CO₂, it will cost large economic loss to reduce CO₂ emission. Therefore MACs of first group of small emitters are low. The other group of small emitters includes Western provinces like Ningxia, Gansu and Qinghai with rising new energy industry. However, there are still metallurgy industries with large CO₂ emission in those provinces. Hence, with relatively small CO₂ emission, MACs of second group provinces are low.

(2) Energy consumption structures

From Fig.4, Coal is main emitter of CO₂ emission in the whole country. The average ratio of CO₂ emission from coal combustion of 30 Chinese provinces is 80%. Coal is mainly used for power generation, production of building materials and domestic-use coal. Besides, Coke, mainly used in metal smelting, is the second large CO₂ emission.

Hebei province, one of the large steel provinces in China, consume large amount of coke for metal smelting. 23% of CO₂ emission came from coke. Diesel oil is mainly used as fuel for large vehicle and vessel. Gasoline is the fuel for compact cars. Blooming trade and large demand in transportation in Shanghai, Guangdong and Zhejiang consume large amount of diesel oil and gasoline. Small amount of kerosene and fuel oil were consumed natural gas is a relatively clean energy. The CO₂ emissions from these three energies were low. It's easier to reduce high- carbon energy's CO₂ emission. Therefore, MAC of Hebei province and Shandong province are low while Beijing and Shanghai are high.

(3) Natural resources

Southern provinces as Hubei, Sichuan and Yunnan provinces have abundant hydro-power. The ratio of hydropower in these three provinces contains 16%, 17% and 14% in 2012. Inner Mongolia Autonomous Region, Hebei and Liaoning provinces have affluent wind power resources as the ratios of installed capacity of wind-driven power are 35%, 10% and 9%. Hydropower and wind power are clean energy and will not produce CO₂ emission. Hence, the MACs of above-mentioned provinces are high.

5. Conclusion and the policy suggestions

5.1 Conclusion

(1) Applying SFA method, MAC results are precise but are 46% less than LP method in this paper as random errors were taken into concerned.

(2) There are no distinct correlation between CO₂ emission and MAC.

(3) Because of different industrial structures, energy consumption structures and natural resources among Chinese provinces, the CO₂ emission and MAC of each province varied.

5.2 Policy suggestions

From the national level, high MAC provinces should reduce more CO₂ emission while the low MAC provinces reduce less CO₂ emission. Therefore, a fair but distinct policy should be proposed.

5.2.1 Change energy production and consumption structures

Coal which contains more than 70% of total primary energy is the dominating energy in Chinese production structure. Crude oil and natural gas only holds less than 10% of total energy. Clean energy which contains hydroelectric, wind electricity and nuclear power attains 10% of all energy. The abundant hydroelectricity resources in Hubei, Sichuan and Yunnan provinces, wind electricity resources in Inner Mongolia, Hebei and Liaoning provinces and the solar power energy which is in a stage of development in lots of Chinese provinces made energy production structure transformation capable.

Coal is also the main consumption energy in all Chinese provinces. Coal combustion caused large amount of CO₂ emission. According to the calculation in this paper, the ratio of CO₂ emission from coal is 88.37%, 92.2% and 91.75% in Shanxi province, Ningxia Hui Autonomous Region and Inner Mongolia Autonomous Region. And it's

not restricts in provinces with abundant coal industry. The average value of ratio of CO₂ emission from coal among nationwide is 80.17%. High CO₂ emission from coal combustion is a nationwide issue. Hence, transform energy consumption structures in all Chinese provinces should be proposed.

5.2.2 Synergetic development in industry structure and economy among provinces

Different industrial structure is one of the reasons that lead to different CO₂ emission and MAC in Chinese provinces. Thermal power, steel and chemical engineering industries are the leading industry in high MAC provinces in Central and Western China. These high CO₂ industries are second industries with low added value. And the MACs are relatively low. Economic development will be destructed if simply reduce large industry production. Synergetic development in industry structure and economy among provinces is more reasonable. Labor, market, environment and policy are the factors which will bring to the industrial transfer. During the development, relatively developed region will prioritize tertiary industry with high additional value and transfer the secondary industry with low additional value into relatively developing region. Pollutions are also move to the developing region. Therefore, policy of synergetic development among developed and developing regions should be proposed. Developed region should compensate developing region which undertake more pollution.

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