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HOW MUCH SHOULD IT PAY TO REDUCE CO_2 EMISSIONS IN CHINA? A PARAMETRIC DISTANCE FUNCTION APPROACH

This study aims to estimate CO_2 emissions-adjusted technical efficiency (CTE) and the shadow price of CO_2 based on input distance function for China. The average value of CTE index is 0.746 indicating that all the provinces could accomplish energy savings and CO_2 emissions reduction of approximately 25.4%. For the abatement cost of CO_2 emissions, we find that the regional economy, on the average, might pay US$ 3.1 to reduce 1 additional ton of CO_2 emissions. The empirical results show that the CO_2 emission trading scheme (ETS) market system could enhance the nationwide cost saving effect. Therefore, we suggest introducing the ETS quickly for China to reduce emissions and gain economic benefits.

Keyword: *shadow price, distance function, CO_2 emission trading scheme, China, technical efficiency.*

Янні Ю, Йонгрок Цой

ПАРАМЕТРИЧНА ФУНКЦІЯ ВІДСТАНІ ДЛЯ ОЦІНЮВАННЯ ВИТРАТ НА СКОРОЧЕННЯ ВИКИДІВ CO_2 В КИТАЇ

У статті оцінено кількість викидів CO_2 з поправкою на технічну ефективність (CTE) і розраховано тіньову ціну CO_2 на основі введення інтервалів у функцію відстані. Середнє значення індекса CTE 0,746 вказує, що всі провінції країни можуть досягти економії енергії і зниження рівня викидів CO_2 приблизно на 25,4%. Для зниження вартості (тобто тіньової ціни) викидів CO_2 розраховано, що регіон має платити у середньому 3,1 дол. США за скорочення однієї додаткової тонни викидів CO_2. Емпіричні результати показали, що впровадження на ринку схеми торгівлі квотами на викиди CO_2 (ETS) може загальнонаціонально підвищити ефект економії витрат. Рекомендовано впровадження ETS найближчим часом задля зменшення кількості викидів у Китаї, від чого країна отримає економічну користь.

Ключові слова: *тіньова ціна, функція відстані, схема торгівлі викидами CO_2, Китай, технічна ефективність.*
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Янни Ю, Йонгрок Цой

ПАРАМЕТРИЧЕСКАЯ ФУНКЦИЯ РАССТОЯНИЯ ДЛЯ ОЦЕНКИ ЗАТРАТ НА СОКРАЩЕНИЕ ВЫБРОСОВ CO_2 В КИТАЕ

В статье оценено количество выбросов CO_2 с поправкой на техническую эффективность (CTE) и рассчитана теневая цена CO_2 на основе введения интервалов в функцию расстояния. Среднее значение индекса CTE 0.746 указывает, что все провинции страны могут достичь экономии энергии и снижения уровня выбросов CO_2 приблизительно на 25.4%. Рассчитано, что для снижения стоимости (т.е. теневой цены) выбросов CO_2 регион должен платить в среднем 3,1 дол. США за сокращение одной дополнительной тонны выбросов CO_2. Эмпирические результаты показали, что внедрение

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на рынке схемы торговли квотами на выброс CO_2 (ETS) может общенационально повысить эффект экономии затрат. Предложено внедрение в ближайщие время квоты ETS с целью уменьшения в Китае количества выбросов, от чего страна получит экономические выгоды.

Ключевые слова: *теневая цена, функция расстояния, схема торговли выбросами CO_2, Китай, техническая эффективность.*

1. Introduction. As a global factory, Chinese economy has been fueled by energy-intense heavy industry and infrastructure, which require enormous amounts of energy and generate many pollutants. China's total energy consumption was 1038.2 mln. TOE, just half of the United States in 2001. However, according to the calculations of BP (2011), China overtook the US and became the world's largest energy user with its energy consumption of 2,434 mln. TOE in 2010, compared to 2,285 mln. TOE in the US same year.

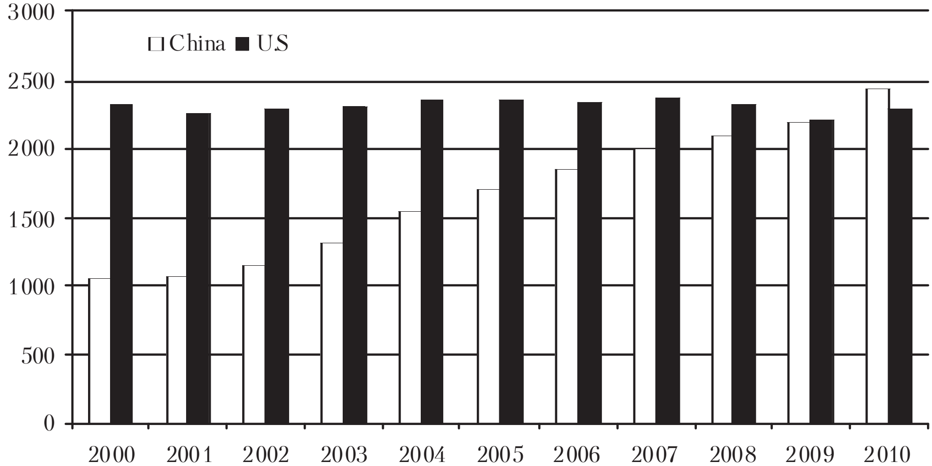

Figure 1. **Energy consumption trend for China and the US, 2000–2010**

In the 12th five-year plan (2011–2015) China announced several new carbon and energy targets based on the 2010 levels: establishment of a carbon market mechanism, improvement of the statistical accounting systems for greenhouse gas emissions, and promotion of a "step by step" establishment of carbon emission trading. The plan includes the establishment of carbon emissions trading schemes (ETS) in the pilot regions of Beijing, Chongqing, Shanghai, Tianjin, Hubei and Guangdong, which will expand to a unified national system until 2015.

Since Chinese government is expected to introduce a carbon ETS, it is very important to estimate the appropriate trading price for carbon emissions and the potential trading cost savings. Therefore, the aim of this paper is to discuss these 2 issues.

There are several analyses of Chinese energy and environmental efficiency as well (Hu and Wang, 2006; Wei et al., 2009; Choi et al., 2012). Unfortunately, previous studies have neglected to incorporate undesirable output CO_2 emissions, resulting in biased estimations of climate change. This study tries to fill this gap by incorporating CO_2 emissions into technical efficiency measurement for China. In addition, for the market pricing of CO_2 emissions trading in China, there are not many studies related to this issue based on the production theory to estimate the marginal abatement costs of CO_2. Therefore, the objective of this study is to estimate environmental technical efficiency and marginal abatement cost of CO_2 based on the production theory. For this purpose, we use the parametric distance function. It is usually used to estimate shadow price of pollutants and the curvature or substitutability along the frontier.

The distance function, originally introduced by Shephard (1970) to incorporate both desirable and undesirable outputs, is broadly used for the estimation of environmentally adjusted productivity and shadow prices for undesirable pollutions. Fare et al. (1993) introduced the Shepherd output distance function to estimate technical efficiency and derive the shadow prices of pollutants. Some studies also employed the Shepherd output distance function (Coggins and Swinton 1996; Swinton, 2002; Lee, 2011). The Shepherd input distance function was used by Hailu and Veeman (2000) first to estimate efficiency and pollutant shadow price. After them, there were also some studies using input distance function (Lee, 2005; Abrate and Erbetta, 2010; Zhou et al., 2010). The input-based approach may prove a more desirable measure, because a proportionate saving in inputs with both good and bad outputs held constant is an unambiguous indicator of welfare change (Hailu and Veeman, 2000). Thus, this study uses the input distance function approach.

The remainder of this paper is as follows. Section 2 defines the input distance function and derives CO_2 emissions-adjusted technical efficiency (CTE) index. Section 2 also derives the shadow price of CO_2. Section 3 presents the data and discusses the carbon emission trading system based on the empirical results. Section 4 concludes the research.

2. Methodology. In the first stage of the model design, we develop CO_2 emission-adjusted technical efficiency (CTE) index based on the Shephard input distance function. In the second stage, we derive shadow prices of CO_2 emissions that indicate marginal costs of CO_2 emissions abatement based on the dual model.

2.1. Input distance function. Consider a production technology in which each province generates a vector of outputs $y \in R_+^2$, using a vector of inputs $x \in R_+^3$. The input vector x contains capital (k), labor (l), and fossil energy (f). The output vector contains gross domestic product (g) and CO_2 emissions (c) as a byproduct of energy consumption. The production technology set could be defined as:

$$T = \{(k, l, f, g, c) : (k, l, f) \text{ can produce } (g, c)\}. \quad (1)$$

Producers cannot affect the abatement of CO_2 emissions without any cost burdens. That is, they incur the opportunity cost of reduced GDP resulting from the diversion of certain inputs for emission abatement efforts. In fact, cleaning up CO_2 emissions requires less fossil fuel consumption; capital investment can be allocated for improvements in fuel efficiency or for increasing dependence on renewable resources (Lee, 2011). As a consequence, we assume that the production technology satisfies the conditions of weak disposability, as suggested by Fare et al. (1989). The weak disposability assumption implies that the reduction of undesirable outputs is not free, whereas a proportionate reduction in both desirable and undesirable outputs is feasible. Additionally, the null-jointness condition also needs to be imposed, thus implying that some undesirable outputs must be generated in order to produce desirable outputs. Technically, the two assumptions can be formulated as:

$$(i)\ \ if\ \{(k,l,f,g,c)\in T,\ for\ \ \delta\in[0,1],\ then\ (k,l,f,\delta g,\delta c)\in T\}$$
$$(ii)\ \ if\ \{(k,l,f,g,c)\in T\ \ and\ \ c=0,\ then\ \ g=0\}. \qquad (2)$$

We define the input distance function introduced by Shephard (1970), which measures the maximum amount by which all inputs can be proportionally reduced while maintaining the level of the final output constant:

$$D(y,x)=\sup\{\theta>0:(x/\theta)\in T\}. \qquad (3)$$

Note that $x \in T$ if and only if $I(y, x) \geq 1$. The distance function is monotonically non-decreasing and concave in inputs and monotonically non-increasing and quasi-concave in outputs; it is also homogenous of degree one in inputs.

From the definition of the input distance function, the degree of technical efficiency (TE) of the Farrell (1957) type can be measured by the reciprocal of the value of the input distance function:

$$TE(y,x)=1/I(y,x). \qquad (4)$$

As the CO_2 emissions (c) are incorporated in the production technology set, therefore, the CO_2 emissions-adjusted technical efficiency (CTE) can be measured by Eq. (4). For instance, Zhou et al. (2010) used this input distance function incorporating CO_2 emissions to measure efficiency of countries.

2.2. Shadow price of CO_2 emissions. In accordance with the findings of Hailu and Veeman (2000), we can also derive pollutant shadow prices that indicate the marginal costs of CO_2 emissions abatement to a producer by using the input distance function. The shadow cost function is defined on the basis of the input distance function as:

$$C^s(y,p^s) = \min_x\{p^s x: I(y, x)\geq 1,\ x\in R^3_+\}, \qquad (5)$$

where $P^s\in R^3_+$ is the input price vector. Shephard (1970) proved that the cost function is dual to the input distance function under regularity conditions; thus, the following duality relationship holds (Fare and Grosskopf, 1990):

$$C^s(y,p^s) = \min_x\{p^s x: I(y, x)\geq 1\}; \qquad (6.1)$$

$$I(y, x)=\min^s_p\{p^s x: C^s(y,p^s)\ \geq 1\}. \qquad (6.2)$$

The shadow price of a given output is defined as its marginal cost. As the input distance function is non-decreasing in bad outputs, the shadow price of bad output is non-positive. If input prices are not available, we can calculate the ratio of the shadow price of 2 outputs. The ratio of shadow prices is equal to the trade-off between 2 outputs with regard to how many units of one good output the producer would be willing to forego for the right to emit one more unit of pollutant output. In other words, this ratio can be interpreted as the marginal rate of transformation between pollution abatement and desirable output.

In this study, if we assume the market price of desirable output of industrial product q to be their shadow price, the shadow price of undesirable output CO_2 emissions in monetary terms can be calculated as follows:

$$p_c^s = p_q^s \times \frac{\partial I(y,x)/\partial c}{\partial I(y,x)/\partial q}. \tag{7}$$

To compute p_c^s in equation (7), a parameterization for $I(y,x)$ is needed. Suppose that the input distance function takes a translog functional form as follows:

$$\begin{aligned} \ln I(y,x) = \alpha_0 + \sum_i \alpha_i \ln x_i + \sum_j \alpha_j \ln y_j + \frac{1}{2}\sum_i \sum_{i'} \gamma_{ii'} \ln x_i \ln x_{i'} \\ + \frac{1}{2}\sum_j \sum_{j'} \gamma_{jj'} \ln y_j \ln y_{j'} + \sum_i \sum_j \beta_{ij} \ln x_i \ln y_j, \\ i,i' = k,l,f, j,j' = q,c. \end{aligned} \tag{8}$$

In accordance with the findings of Aigner and Chu (1968), and Hailu and Veeman (2000), a linear programming technique can be used to compute the parameters in equation (10) as follows:

$$\begin{aligned} & Min \sum_h [\ln I(y^h, x^h) - \ln 1] \\ & s.t. \ln D(y^h, x^h) \geq 0; \\ & \partial \ln D(y^h, x^h)/\partial \ln q^h \leq 0; \\ & \partial \ln D(y^h, x^h)/\partial \ln c^h \geq 0; \\ & \partial \ln D(y^h, x^h)/\partial \ln x^h \geq 0; \\ & \sum_i \alpha_i = 1, \sum_{i'} \gamma_{ii'} = \sum_i \beta_{ij} = 0. \end{aligned} \tag{9}$$

The objective function $Min\Sigma_j$ [ln $I(y^j,x^j)$ – ln1] means that the input distance function should be minimized, whereas j = 1, ..., J indicates the sector observations. ln $I(y^j,x^j) \leq 0$, since $I(y,x) \leq 1$. For the monotonicity condition, $\partial \ln I(y^j,x^j) / \partial \ln x^j \geq 0$, $\partial \ln I(y^j,x^{jj}) / \partial \ln q \leq 0$ and $\partial \ln I(y^j,x^{jj}) / \partial \ln c \geq 0$. For the imposition of linear homogeneity in inputs, $\Sigma_x\alpha_x = 1$, $\Sigma_{x'}\beta_{x'} = \Sigma_x\gamma_{xx} = 0$. Finally, symmetry is also assumed.

3. Empirical Findings and Discussion.

3.1. Data. Considering that our research focuses on regional economy, GDP at current price was selected as the only desirable output; this has also been the case in many previous studies (e.g., Hu and Wang, 2006; Choi et al., 2010; Bian and Yang, 2010; Yeh et al., 2010). Labor and capital are the 2 basic non-energy inputs, and thus the present paper used the employed labor number (1,000 persons) to represent labor input. Moreover, the capital stock as of 2009 is estimated via the perpetual inventory approach:

$$K_{i,t} = I_{i,t} + (1-\delta_i)K_{i,t}, \tag{10}$$

where $I_{i,t}$, δ_i and $K_{i,t}$ represent the gross investment, depreciation rate, and capital stock for sector i at time t, respectively. The capital stock and depreciation data are available in Wu (2009). All the monetary variables including GDP and capital stock are measured in the prices of 2009 and then transformed into US$ basing on the exchange rate 1US$ = 6.83Y.

Energy consumption is selected as energy input, including all types of energy such as coal, oil, and gas, all of which are converted into tons of standard coal equivalent (TCE) in terms of the corresponding conversion rate of energy folding. Official statistics regarding provincial CO_2 emission are not available. According to the Intergovernmental Panel on Climate Change (IPCC, 2006) guidelines for calculating CO_2, the transformation formula for CO_2 emissions from fossil fuels is:

$$CO2 = \sum^{n} A \times CCF_i \times HE_i \times COF_i \times (44/12). \quad (11)$$

CO_2 emissions are related to the amount of all carbonaceous fuel combusted (A), carbon content factor (CCF), heat equivalent (HE), and carbon oxidation factor (COF) of the carbonaceous fuel. The number (44/12) represents the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12). *i* represents a type of carbonaceous fossil fuel. The Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC, 2007) in China previously published listings of the CO_2 emission factors of major types of carbonaceous fuels, as shown in Table 1.

Table 1. **CO_2 emission factor by major carbonaceous fuel in China**

Fuels	Coal	Petrol	Kerosene	Diesel	Fuel oil	Natural gas
CCF*	27.28	18.9	19.6	20.17	21.09	15.32
HE*	192.14	448	447.5	433.3	401.9	0.384
COF (%)	92.3	98.0	98.6	98.2	98.5	99.0

* CCF and HE are expressed in units of tons carbon/trln. Joules, and trln. Joules/10^4 tons (m^3), respectively.
Source: NDRC, 2007.

We then collected the data of inputs and outputs in our framework. Energy input data for Tibet could not be obtained; thus, we employed a dataset encompassing 30 of 31 provinces. Table 2 shows the descriptive statistics of the data.

Table 2. **Descriptive statistics of inputs and outputs, 2009, n = 30**

Inputs & Outputs	Variable	unit	Mean	Max	Min	Std.dev.
Non-energy inputs	Capital*	10^9 US$[a]	493	970	166	330
	Labor**	10^3 persons	4184	10550	506	2477
Energy inputs	Energy***	10^3 tons	134999	363372	14061	84416
Desirable output	GDP**	10^9 US$[a]	187	607	17	149
Undesirable	CO_2*	10^3 tons	331559	892442	34533	207327

* Estimated by the authors.
** China Statistical Yearbook 2010 (NBSC, 2010a).
*** China Energy Statistical Yearbook 2010 (NBSC, 2010b).
[a] Capital and GDP are converted into US$ basing on the 2009 exchange rate (1$ = 6.83Y).

3.2.CO_2 emissions adjusted technical efficiency. Table 3 presents the parameter estimates for translog Eq. (8), which are obtained by solving the linear programming constraint of (9). The values of the input distance function for each province are calculated via the substitution of these estimates into equation (8).

According to the classifications of Chinese regions, provinces are divided into 3 groups – East, Central and West (Hu and Wang, 2006). The East area is composed of 11 regions: 8 coastal provinces. The Central area – of 10 inland provinces. The West area covers more than half of China's territory. Compared with the other 2 areas, this area has the lowest population density and is the least developed area in China.

Table 3. **Parameter estimates of translog input distance function**

Parameter	Estimate	Parameter	Estimate
α_0	0.5691	γ_{kf}	-0.3709
α_q	-0.8468	γ_{ll}	-0.3815
α_c	-0.0057	γ_{lf}	0.2797
α_k	0.3277	γ_{ff}	0.0912
α_l	0.6442	β_{kq}	0.0491
α_f	0.0281	β_{kc}	0.0117
γ_{qq}	0.0687	β_{lq}	-0.0547
γ_{qc}	-0.0046	β_{lc}	-0.0031
γ_{cc}	0.0048	β_{fq}	0.0056
γ_{kk}	0.2691	β_{fc}	-0.0086
γ_{kl}	0.1018		

Using equations (3) and (4), we can calculate the CO_2 emissions adjusted technical efficiency (CTE).

With regard to CTE, the results demonstrate that most provinces in China are not performing carbon-adjusted technology efficiently, as they use massive energy resources to achieve scale-oriented economic growth. CTE scores vary from 0.583 to 1, with the average value of 0.746, indicating that all the provinces nationwide could accomplish energy savings of approximately 25.4%, if each province operates on the boundary of production technology. This huge amount of reduction possibility leads to the conclusion that regional economies are not technically efficient, and thus, it is clearly possible to reduce the huge amounts of carbon energy input.

From the view of each province, Beijing, Guangdong and Jiangsu evidenced the highest environmental technical efficiency score of 1, indicating that these 3 regional performances of CO_2 efficiency could be the benchmarkers for other provinces. Guizhou shows the lowest environmental technical efficiency score of 0.583.

For the regional comparison in Table 4, the results demonstrate that the technical efficiency for 3 local areas of China show considerable differences. The average efficiency of the Eastern area was 0.867, followed by the Central area (0.709) and then Western (0.646). This regional difference is statistically significant by the Kruskal-Wallis test, at the significance level of 5%. The results are similar to some previous studies based on nonparametric approach such as Shi et al. (2010) and Yeh et al. (2010) which showed that the East has higher energy efficiency or environmental efficiency than other 2 areas. This implies that higher economic development could be matched with better environmental technical efficiency, which is mishap to enlarge the bipolarization of Chinese economy. This can be interpreted as follows: the East is more developed and economically advanced and thus the government can allocate more capital for rapid economic growth in the area and this allocation of capital surplus may promote the energy efficient technologies for its sustainable development. Or this economically well-developed area may transfer its environmentally harmful portion of production process to underdeveloped West. In order to avoid this economic bipolarization as well as social inequitable allocation of economic activities, Chinese government should provide a more systematic and equitable political paradigm for sustainable development in all the regions. One of these solutions could be the systematic utilization of ETS on the production procedural basis.

Table 4. **Technical efficiency and shadow price of CO_2**

Province	Region	CET	Shadow price ($/T)
Anhui	Central	0.761	2.3
Beijing	East	1.000	10.0
Chongqing	West	0.717	2.9
Fujian	East	0.817	2.6
Gansu	West	0.600	2.9
Guangdong	East	1.000	1.2
Guangxi	West	0.737	2.8
Guizhou	West	0.583	2.0
Hainan	East	0.762	16.9
Hebei	East	0.713	0.8
Heilongjiang	Central	0.662	2.0
Henan	Central	0.723	1.1
Hubei	Central	0.711	1.4
Hunan	Central	0.725	1.4
Inner Mongolia	Central	0.719	1.1
Jiangsu	East	1.000	1.2
Jiangxi	Central	0.792	3.7
Jilin	Central	0.720	2.6
Liaoning	East	0.705	1.1
Ningxia	West	0.593	4.1
Qinghai	West	0.595	6.5
Shaanxi	Central	0.698	2.3
Shandong	East	0.806	0.8
Shanghai	East	0.973	2.8
Shanxi	Central	0.590	1.1
Sichuan	West	0.687	1.1
Tianjin	East	0.885	4.5
Xinjiang	West	0.594	2.3
Yunnan	West	0.638	2.2
Zhejiang	East	0.876	1.5
Average	China	0.746	3.1
	East	0.867	3.9
	Central	0.709	2.1
	West	0.646	2.8

3.3. Shadow price of CO_2. As shown in Table 4, the estimated shadow prices of CO_2 from equation (9) can be interpreted as measures of the opportunity cost of additional CO_2 abatement in terms of GDP converted into dollar values. Therefore, the shadow price measures the marginal abatement cost of CO_2 to manufacturers and the society overall.

Table 4 shows that the regional economy, on average, could pay $3.0 to abate 1 additional ton of CO_2 emissions. Hainan province and Beijing evidenced the highest CO_2 marginal abatement costs, which were 16.9$/T and 10.0$/T, respectively.

Hebei and Shandong achieved the lowest CO_2 shadow price, at 0.8$/T. Hainan, probably well-positioned for the best conditions on the air and thus additional CO_2 emissions, may create much harder burden than any other province. This makes it very difficult to abate additional CO_2 emissions in Hainan, incurring highest shadow price for CO_2 emissions in terms of CO_2 marginal abatement costs. For Shandong, the case is directly opposite. Since Shandong has much more manufacturers with high use of fossil inputs that lead to high emission level, the additional CO_2 emissions in Shandong may incur lower marginal costs than other provinces.

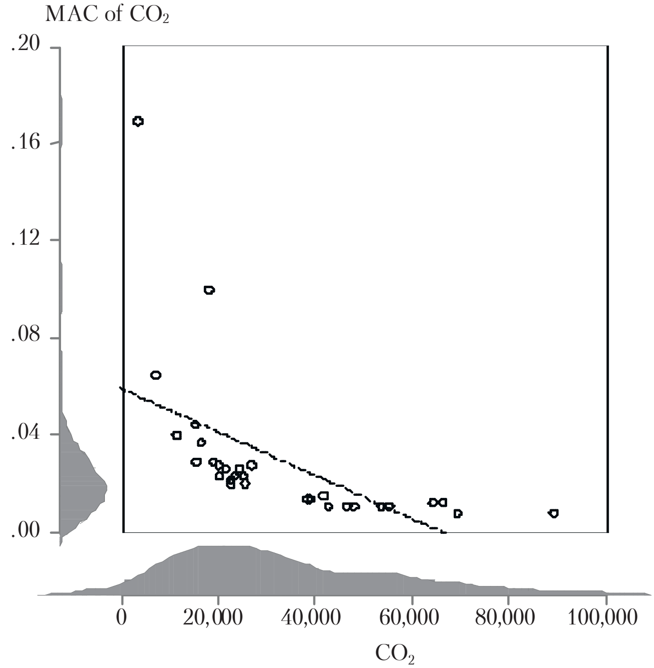

Figure 2. **Plotting graph of MAC of CO_2 and emissions amount**

Based on the estimation, if the carbon emission trading market can be properly formulated, free market price could be between minimum price of 0.8$ and the maximum of 16.9$ per ton in theoretical terms. The estimation result of CO_2 shadow price in this study is lower than the international CO_2 emissions trading market price. For instance, the current international market price for carbon emission trading is quoted as 12.22 EUR/T (16 US$) at the EU market as of July 2011 on the Thomson Reuters website. The reason of lower CO_2 shadow price in China may be interpreted as follows; according to Turner et al. (1993), the marginal abatement cost of CO_2 emission is negatively related to the amount of the pollutant. If the emission amount is large, the marginal abatement cost will be relatively low. However, if the emission amount is small, marginal abatement cost will be relatively high. This difference coming from the current status of environmental condition may infer the fact that Chinese economy generates significantly higher CO_2 emissions than any other country. Thus, it may incur a lower cost for additional abatement of CO_2 emissions than in other countries. This negative relation between marginal abatement cost (MAC) of CO_2 emissions and the amount of CO_2 emissions in this study can be found in Figure 2.

3.4. Potential cost saving in carbon emission trading. According to the 12th five-year plan of Chinese government, carbon ETS's are inaugurated in some pilot regions such as Shanghai from 2011. This pilot system shall be expanded for a unified national system until 2015. If CO_2 emission standards are enforced by regulation and carbon emission trading markets formulated in China, we will estimate the cost saving by carbon emission trading from our empirical results.

As the energy and CO_2 reduction targets have been assigned to provinces in 2012, recently, each province is facing its CO_2 reduction target. If the emission trading scheme is introduced in China, how strong the cost saving effect will be? In an effort to answer this question, we use Beijing as an exemplary case study for simulated implications.

Assume that CO_2 emissions are regulated for Beijing to reduce T tons (T = 1 mln. tons) from the current condition; how much cost then could be reduced? If Beijing does not use CO_2 emission trading and abates CO_2 emission by itself, it will cost $10 mln. (MAC of Beijing $ x regulation amount T). If CO_2 emission trading is allowed, Beijing could buy CO_2 emission directly from other provinces at a much lower rate. Suppose that Beijing can buy the CO_2 emissions directly from Hebei and the market price is 0.8–10$ per ton, the price will be between the CO_2 emission abatement costs of Beiing and Hebei. If the market price is higher than 10$, Beijing will not buy it, and if the market price is lower than 0.8$, Hebei will not be willing to trade in the abated CO_2 emissions for Beijing. It depends on the negotiation power between these ceiling and floor shadow prices.

The cost saving in Beijing will be higher than 0 (if the market price is 10$) and smaller than $9.2 mln. (when the market price is 0.8$), while the potential profit of Hebei is larger than 0 (if the market price is 0.8$) and smaller than $9.2 mln. (when the market price is 10$). Thus, all the provinces could get the benefits from the ETS market system. This generates a significant signal for the CO_2 emission producers to abate their emissions and more aggressively employ environmental technical efficiency measures. Chinese government may employ its pumping policies for the market to be more sensitive with equitable incentives, especially for the less advantageous regions of the East. As CO_2 emissions abatement is clearly feasible, it is much easier for the government to manage earlier inauguration of effective market system without a great deal of conflict when it advances environmental technical efficiency measures targeted at the appropriate shadow price. The case study emphasizes that the CO_2 emission trading scheme (ETS) market system could enhance the nationwide cost saving effect. Therefore, we suggest that policymakers should introduce the ETS more aggressively and proactively for China's regional economy to reduce the overall emission and gain additional economic benefits from cost saving in a marketable way.

4. Conclusions. Most previous studies have been unable to provide specific details on cost saving effect in Chinese carbon emissions trading. This study contributes to the current body of relevant literature by exploring technical efficiency, energy saving potential and potential cost saving under Chinese carbon emissions trading market scheme in more detail. Carbon-adjusted technical efficiency (CTE), at the average value of 0.746, reflecting poor energy usage conditions, could be enhanced by approximately 25.4% of input saving if provinces operate at the boundary of production technology. For the shadow price of CO_2 emissions, we determine herein that regional economy, on average, could pay $3.1 to abate 1 additional ton of CO_2 emissions. Because of regional differences in their abatement costs, there are strong incentives for provinces to participate in a mutually beneficial ETS system. The case study of Beijing clearly shows that potential cost savings are achievable via carbon emission trading. Therefore, we suggest that policymakers should introduce the ETS more aggressively for China to reduce emissions and gain economic benefits.

References:

Abrate, G., Erbetta, F. (2010). Efficiency and patterns of service mix in airport companies: An input distance function approach. Transport Res. E-Log., 46: 693–708.

Aigner, D., Chu, S. (1968). On estimating the industry production function. Am. Econ. Rev., 58: 826–839.

Bian, Y., Yang, F. (2010). Resource and environment efficiency analysis of provinces in China: A DEA approach based on Shannon's entropy. Energy Policy, 38: 1909–1917.

BP (2011). Statistical Review of World Energy. Available at: http://www.bp.com/statisticalreview.

Choi, Y., Lee, E.Y., Wu, D.D. (2010). The risk-effective sustainability of policies: The small business credit environment in Korea. Int. J. Environ. Pollut., 42: 317–329.

Choi,Y., Zhang, N., Zhou, P. (2012). Efficiency and abatement costs of energy-related CO_2 emissions in China: A slacks-based efficiency measure. Applied Energy, 98: 198–208.

Coggins, J.S., Swinton, J.R. (1996). The price of pollution: a dual approach to valuing SO2 allowance. J.Environ.Econ.Manag., 30: 58–72.

Fare, R., Grosskopf, S. (1990). A distance function approach to price efficiency. J. Public Econ., 43: 123–126.

Fare, R., Grosskopf, S., Lovell, C.A.K., Pasurka, C. (1989). Multilateral Productivity Comparisons When Some Outputs are Undesirable: A Nonparametric Approach. Rev. Econ. Stat., 71: 90–98.

Fare, R., Lovell, C.A.K., Yaisawarng, S. (1993). Derivation of shadow prices for undesirable outputs: a distance function approach. Rev. Econ. Stat., 75: 374–380.

Farrell, M.J. (1957). The measurement of productive efficiency. J.Roy. Stat. Soc., 120: 253–290.

Hailu, A., Veeman, T.S. (2000). Environmentally sensitive productivity analysis of the Canadian pulp and paper industry, 1959–1994: an input distance function approach. J. Environ. Econ. Manag., 40: 251–274.

Hu, J.L., Wang, S.C. (2006). Total-factor energy efficiency of regions in China. Energy Policy, 34: 3206–3217.

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html.

Lee, M. (2005). The shadow price of substitutable sulfur in the US electric power plant: A distance function approach. J.Environ. Manag., 77: 104–110.

Lee, M. (2011). Potential cost savings from internal/external CO_2 emissions trading in the Korean electric power industry. Energy Policy, 39: 6162–6167.

National Bureau of Statistics of China (NBSC) (2010a). China Energy Statistical Yearbook 2010. China Statistics Press, Beijing.

National Bureau of Statistics of China (NBSC) (2010b). China Statistical Yearbook 2010. China Statistics Press, Beijing.

National Development and Reform Commission (NDRC) (2007). National Greenhouse Gas Inventory of the People's Republic of China (In Chinese). Chinese Environmental Science Press, Beijing.

Shephard, R.W. (1970). Theory of Cost and Production Functions. Princeton University Press.

Shi, G.M., Bi, J., Wang, J. (2010). Chinese regional industrial energy efficiency evaluation based on a DEA model of fixing non-energy inputs. Energy Policy, 38: 6172–6179.

Swinton, J.R. (2002). The Potential for Cost Savings in the Sulfur Dioxide Allowance Market: Empirical Evidence from Florida. Land Econ., 78: 390–404.

Turner, R.K., Pearce, D., Bateman, I. (1993). Environmental Economics: An Elementary Introduction. Johns Hopkins University Press, Baltimore.

Wei, C., Ni, J., Shen, M. (2009). Empirical Analysis of Provincial Energy Efficiency in China. China World Econ., 17: 88–103.

Wu, Y. (2009). China's Capital Stock Series by Region and Sector. The University of Western Australia Discussion Paper 09.02.

Yeh, T., Chen, T., Lai, P. (2010). Incorporating greenhouse gas effects to evaluate energy efficiency in China. Int. J. Sust. Dev. World, 17: 370–376.

Zhou, P., Ang, B.W. (2008). Linear programming models for measuring economy-wide energy efficiency performance. Energy Policy, 36: 2911–2916.

Zhou, P., Ang, B.W., Han, J.Y. (2010). Total factor carbon emission performance: A Malmquist index analysis. Energy Econ., 32: 194–201.

Zhou, P., Ang, B.W., Poh, K.L. (2008). A survey of data envelopment analysis in energy and environmental studies. Eur. J. Oper. Res., 189: 1–18.

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