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Working Paper 94
http://ceep.bit.edu.cn/english/publications/wp/index.htm

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June 2016

This paper can be cited as: *Wang K. 2016. Potential carbon emission abatement cost recovery from carbon emission trading in China: an estimation of industry sector. CEEP-BIT Working Paper.*

Ke Wang gratefully acknowledges the financial support from the National Natural Science Foundation of China (grant nos. 71471018, 71521002 and 71101011), and the Basic Scientific Research Foundation of BIT (grant no. 20152142008). The views expressed in this paper are solely authors' own and do not necessarily reflect the views of the supporting agencies and Beijing Institute of Technology. The authors alone are responsible for any remaining deficiencies.

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Potential carbon emission abatement cost recovery from carbon emission trading in China: an estimation of industry sector

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Abstract

Purpose

This study provides an estimation of CO_2 emission abatement costs in China's industry sector during the period of 2006-2010, and additionally provide an ex-post estimation of CO_2 abatement cost savings that would be realized if carbon emission permits trading among different industry sectors of 30 provinces in China during the same period was allowed, in order to answer the question that whether the industrial carbon emission abatement cost can (partially) be recovered from carbon emission trading in China.

Design/methodology/approach

The joint production framework associated with the environmental technology is utilized for formulating the models for estimating abatement costs and simulating emission permits trading scheme. Several Data Envelopment Analysis (DEA) based models that could deal with both the desirable and undesirable outputs with in the above framework is utilized for abatement cost saving estimation. The weak disposability assumption and variable returns to scale assumption are applied in the modelling.

Findings

In China's industry sector, during 2006-2010: (i) The estimated CO_2 emission abatement cost is 1842 billion yuan which accounts for 2.45% of China's total industrial output value; (ii) The emission abatement cost saving from emission permits trading would be 315 billion yuan, which accounts for 17.12% of emission opportunity abatement cost. (iii) Additional 1065.95 million tons of CO_2 emission reductions would be realized from emission permits trading, and this accounts for 4.75% of the total industrial CO_2 emissions.

Research limitations/implications

The estimation is implemented at the regional level, i.e., the emission permits trading subjects are the whole industry sectors in different Chinese provinces, because of the data limitation in this study. Further estimation could be implemented at the enterprise level in order to provide a deeper insight into the abatement cost recovery from emission permits trading.

Practical implications

The estimation models and calculation process introduced in this study could be applied for evaluating the efficiency and effectiveness of pollutant emission permits trading schemes from the perspective that whether these market-based abatement policy instruments help to realize the potential abatement cost savings.

Originality/value

To the best of our knowledge, no study has provided the estimation of CO_2 emission abatement cost and the estimation of CO_2 abatement cost saving effect from emission permits trading for China's industry sector. This study provides the first attempt to fill this research gap.

1 Introduction

China plays an important role in the effort of global warming mitigation because it is the largest fossil fuel consumer and the largest greenhouse gas emitter in the world since 2009. The industry sector is a key sector for China's economic growth and sustainable development since it accounts for more than 60% of China's final energy consumption, contributes more than 40% of China's GDP, and accounts for more than 60% of China's total CO_2 emissions in 2014. From 2006, China had implemented several policies for achieving the joint goal of economic growth and CO_2 emission control especially in industry sector. These policies included command-and-control regulations and market-based schemes. Mandatory energy intensity (energy consumption / GDP) reduction target were proposed in the 11th Five-year plan period (2006-2010) that the intensity is required to reduce by 20% in 2010 compared with the 2005's level. The policies such as Shut-down of Small Thermal Power Units Action, Energy Saving Actions for Thousand and Ten Thousand Enterprises, Eliminating Backward Production Capacity Action, Key Energy Conservation Projects and Energy Efficiency Label Action are implemented during this period for achieving the national energy saving and associated CO_2 emission control target. Most of the above policy instruments are considered command-and-control policy instruments; while the market-based policy instruments especially emission permit trading has not been implemented for energy saving and emission control during 2006-2010.

The CO_2 emission permit trading scheme is considered a market-based policy instrument for achieving a reduction in carbon emissions at the minimal abatement cost (Kunsch et al., 2004) and the heterogeneity in emission abatement cost determines the advantage of a CO_2 emission permit trading policy over a command-and-control policy in the effort of emission reduction (Carlson et al., 2000; Rong and Lahdelma, 2007). This study attempts to estimate the CO_2 emission abatement cost from command-and-control emission reduction activities and to discover the abatement cost saving if the CO_2 emission permit trading scheme was implemented during 2006-2010 in China's industry sector.

A few previous studies have attempted to estimate the impact of emission permit trading in China. For instance, Zhou et al. (2013) assessed the impact of China's regional trading of carbon emission reduction quotas and pointed out that approximately 40% of total emission abatement cost saving can be realized through emission trading. Cui et al. (2014)'s calculation of the cost saving from CO_2 emission permit trading in China shown that an up to 23% abatement cost may achievable by 2020. Wang et al. (2015) estimated the potential gains from spatial and spatial-temporal carbon emissions permits trading in China and found out that an average percentage of 10.8% and 5.9% potential abatement cost savings would be realized during 2006-2010. These studies provided good examples of abatement cost saving estimations for China; however, to the best of our knowledge, no study has provided the estimation of CO_2 emission abatement cost and the estimation of CO_2 abatement cost saving effect from emission permit trading for China's industry sector. This study gives the first attempt to fill this research gap.

In this study, the CO_2 emission abatement cost is estimated by calculating the difference between the maximum amounts of total industrial output values that China's industry sector could achieve with and without environmental regulations (i.e., with and without constraints on energy conservation and emission reduction) following the method of Färe et al. (2007a). Then, the potential gains that can be obtained by CO_2 emission permit trading are estimated for China's industry sector following the methods proposed in Brännlund et al. (1998) and extended and applied in Färe et al. (2014) and Wang et al. (2015). The potential gains represent the potential recoveries on total industrial output value loss (caused by emission abatement activities in industry sector) through implementing an emission permit trading scheme instead of a command-and-control regulation. Therefore, the estimated potential gains can be used as a represent of the CO_2 emission abatement cost saving if CO_2 emission permits were tradable among different regional industry sectors in China.

Section 2 and 3 introduce the models for estimating emission abatement costs and estimating abatement cost savings; Section 4 reports and discusses the estimation results; Section 5 concludes this paper.

2 Models for estimating emission abatement costs

Since both the desirable outputs (industrial products) and the undesirable outputs (industrial carbon and other pollution emissions) need to be modeled simultaneously, the joint production approach associated with environmental technology (Färe et al., 2007a) is utilized for formulating the abatement cost estimation models. Suppose we have n observations or decision making unites (DMUs), i.e., industry sector of provinces in this study, which is denoted by DMU_j, j=1,...,n. The nonnegative m dimensional input, s dimensional desirable output and h dimensional undesirable output vectors are denoted by $\boldsymbol{x}=(x_{ij},\ i=1,\ldots,m;\ j=1,\ldots,n)$, $\boldsymbol{y}=(y_{rj},\ r=1,\ldots,s;\ j=1,\ldots,n)$ and $\boldsymbol{b}=(b_{fj},\ f=1,\ldots,h;\ j=1,\ldots,n)$, respectively. Then, the output set that models the environmental technology can be written as $P(\boldsymbol{x})=\{(\boldsymbol{y}, \boldsymbol{b}) \mid \boldsymbol{x} \text{ can produce } (\boldsymbol{y}, \boldsymbol{b})\}$. The environmental technology satisfies the standard properties of technology (Färe et al., 2007b) including: inactivity is possible; production set is compact; inputs and desirable outputs are freely disposable;

undesirable and desirable outputs are jointly weakly disposable and null-joint. A more detailed discussion on environmental technology can be found in Färe et al. (2016), and an introduction on the regular production technology within the DEA framework can be found in Tan et al. (2008), Wang et al. (2010) and Tsolas (2014). It should be noticed that the weak disposability assumption has a few disadvantage, for example, it may violate the first law of thermodynamics. In this study, we apply this assumption because of the concerns as below. It treats undesirable outputs as outputs but not inputs so as to reflect the real production process. It appropriately describes the tight relationship between desirable and undesirable outputs. The drawback of the existence of strongly dominated projection in weak disposability can be detected and discarded through an appropriate choice of direction for projection.

In this study, only one desirable output, i.e., total industrial output value, is produced, we could first calculate the largest accessible total industrial output value $\tilde{y}_k^t$ when undesirable outputs are unregulated for observation k as follows:

$$\begin{aligned} R_k^{NR} &= \max \tilde{y}_k \\ \text{s.t. } & \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{ik}, i = 1, \dots, m, \\ & \sum_{j=1}^{n} \lambda_j y_j \ge \tilde{y}_k, \\ & \sum_{j=1}^{n} \lambda_j = 1, \\ & \lambda_j \ge 0, j = 1, \dots, n. \end{aligned} \qquad (1)$$

where x_{ik} is the ith input used by the kth observation and λ_j is the intensity variable. The constraint $\sum_{j=1}^{n} \lambda_j = 1$ is imposed indicating variable returns to scale (VRS). The optimized objective value R_k^{NR} represents the maximum amount of total industrial output value that can be produced by industry sector of province k supposing there are no emission regulations (NR) on the production of undesirable outputs, i.e., each DMU is able to freely dispose its byproducts and therefore no constraint is imposed on undesirable output in (1).

Then, we utilize the following model to calculate the largest accessible total industrial output value $\tilde{y}_k$ for industry sector of province k when undesirable outputs are regulated, i.e., there are emission restrictions on the production of undesirable outputs:

$$
\begin{aligned}
R_k^{NT} &= \max \tilde{y}_k \\
\text{s.t.} \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{ik}, i = 1,\dots,m \\
& \sum_{j=1}^{n} \theta_j \lambda_j y_j \ge \tilde{y}_k, \\
& \sum_{j=1}^{n} \theta_j \lambda_j b_{fj} \le b_{fk}, f = 1,\dots,h, \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \lambda_j \ge 0, j = 1,\dots,n.
\end{aligned} \tag{2}
$$

where b_{fk} is the fth undesirable output of the kth industry sector of province. The constraints on undesirable output introduce environmental regulations associated with weak disposability assumption. Note that the specification of the undesirable output constraint, i.e., the imposing of θ_j associated with both desirable and undesirable outputs, and the "≤" constraint, guarantees the jointly scales down on outputs and avoids the possibility of a downward sloping portion of production frontier (Färe et al., 2014; Lee 2015). The optimized objective value R_k^{NT} represents the maximum amount of total industrial output value that can be produced by industry sector of province k under the situation that there are regulations, i.e., emission permits, on undesirable outputs, but the emission permits are not tradable (*NT*) among different regions. Model (2) is a non-linear programming that ban be simply linearized through setting $\theta_j \lambda_j = \mu_j$, $(1-\theta_j)\lambda_j = \omega_j$. A detailed explanation on the linearization can be found in Wang et al. (2015). The primary difference between (1) and (2) is the imposing of the constraints on the undesirable outputs in (2) which indicate that each DMU is not allowed to freely dispose its undesirable outputs to environment.

Based on the calculations of maximum amount of desirable outputs with and without environmental regulations on undesirable outputs, the emission opportunity abatement cost (*OAC*) of observation k can be obtained as follows:

$$
OAC_k = R_k^{NR} - R_k^{NT} \quad (3)
$$

OAC measures the reduced desirable output when the undesirable output is not freely disposable. *OAC*>0 indicates emissions abatement activities are associated with desirable output reduction; while *OAC*=0 implies that desirable output is not reduced with emissions abatement activities.

3 Models for estimating abatement cost savings

The emissions abatement cost is defined as the opportunity cost of emissions abatement activities in Section 2. In this section, following Brännlund et al. (1998) and Färe et al. (2013 and 2014), we additional take the emission permit trading into the account of abatement cost saving estimation.

As mentioned above, R_k^{NT} in (2) represents the maximum total industrial output value of industry sector of province k under the condition that the emissions are regulated, for example with emission permits, instead of being able to freely disposed into environment, and in addition, these emission permits are not allowed to be reallocated among different industry sectors of provinces. Therefore, R_k^{NT} also can be considered as the maximum amount of total industrial output value under the command-and-control (on undesirable outputs) situation that each industry sector of province k is only allowed to produce b_{fk} amount of undesirable outputs. Moreover, the aggregated maximum total industrial output value of all DMUs under estimation is $R^{NT} = \sum_{k=1}^{n} R_k^{NT}$.

Next, we introduce the following model to estimate the maximum total amount of total industrial output value $\sum_{k=1}^{n} \tilde{y}_k$ for all industry sectors of all provinces under estimation when emission permits are tradable, i.e., allowed to be reallocated, among industry sectors of provinces:

$$
\begin{aligned}
R^{ST} &= \max \sum_{k=1}^{n} \tilde{y}_k \\
s.t.\ & \sum_{j=1}^{n} \lambda_j x_{ij} \le x_{ik}, i = 1, \dots, m, k = 1, \dots, n, \\
& \sum_{j=1}^{n} \theta_j \lambda_j y_j \ge \tilde{y}_k, k = 1, \dots, n, \\
& \sum_{j=1}^{n} \theta_j \lambda_j b_{fj} \le \tilde{b}_{fk}, f = 1, \dots, h, k = 1, \dots, n, \quad (4) \\
& \sum_{j=1}^{n} \lambda_j = 1, \\
& \sum_{k=1}^{n} \tilde{b}_{fk} \le \sum_{j=1}^{n} b_{fj}, f = 1, \dots, h \\
& \mu_j, \omega_j \ge 0, j = 1, \dots, n.
\end{aligned}
$$

Note the constraint $\sum_{k=1}^{n} \tilde{b}_{fk} \le \sum_{j=1}^{n} b_{fj}$ implies that the aggregated undesirable outputs after emission permit reallocation should not exceed the aggregated allowed or observed emission level. The linearization of Model (4) can be found in Wang et al. (2015).

The optimized objective value R^{ST} represents the maximum total amount of total industrial output value of all n industry sector of provinces when the emission permits are spatially tradable (*ST*), and $R_k^{ST} = \tilde{y}_k$ represents the maximum amount of total industrial output value of each industry sector of province k under the spatial emission permit trading situation.

Similarly, we could define the emission abatement cost saving from spatial trading of emission permits (*ACS*) of observation k as follows:

$$ACS_k = R_k^{ST} - R_k^{NT} \quad (5)$$

ACS measures the abatement cost recovery from eliminating spatial regulatory rigidity on emission permit reallocation, i.e., the abatement cost saving from allowing spatial emission permit trading. $ACS>0$ indicates that emission permit spatial trading leads to abatement cost saving; while $ACS=0$ indicates spatial emission permit trading is not associated with abatement cost saving.

4 Ex-post estimation for China's regional industry sectors

The emission opportunity abatement cost (*OAC*) is defined as the lost total industrial output value associated with emission abatement activities; while the abatement cost saving (*ACS*) is defined as the abatement cost recovery associated with the reallocation of undesirable outputs, i.e., emission permit trading among different industry sectors of different provinces. In this section, we apply the approaches proposed above to estimate the carbon emission abatement cost as well as the abatement cost saving from emission permit trading through an ex-post analysis for China's industry sector so as to provide an answer to the question that can carbon emission abatement cost be (partially) recovered by carbon emission trading.

4.1 Data

The data for ex-post estimation consist of the industry sectors in China's 30 provincial level regions over the period of 2006-2010. Our estimation consist of one desirable output: total industrial output value; one undesirable output: carbon dioxide (CO_2) emissions from fuel combustion in industry sector; and three inputs: fix assets, labor and energy of industry sector. The data are collected from China Industry Economy Statistical Yearbook (2007-2011) and China Energy Statistical Yearbook (2007-2011). The data on industrial energy consumption are collected from the energy balance pivot table of each province, which are additionally converted into coal equivalent (ce) according to the conversion factors listed in the China Energy Statistical Yearbook. The data on CO_2 are estimated based on the consumption of fossil fuel in industry sector and the carbon emission factors for fossil fuel combustion suggested by Intergovernmental Panel on

Climate Change. A more detailed interpretation on the estimation of CO_2 can be found in Wang et al. (2013, 2014). Because the energy consumption and the CO_2 emissions from fuel combustion in industry sector are separately calculated based on the consumption of coal, oil and natural gas, it can be guaranteed that the estimated CO_2 emissions are neither proportional to total fuel consumption nor proportional to specific energy consumption (i.e., coal, oil, or natural gas). This helps to increase the effectiveness of the evaluation in this study. The descriptive statistics of the input and output data are listed in Table 1.

Table 1 Input and output data

Inputs and outputs	Year	Mean	Std. Dev.	Maximum	Minimum
Fixed assets of industry sector (Billion yuan)	2006	421.04	342.81	1306.97	60.59
	2007	454.36	373.59	1453.16	57.22
	2008	511.65	419.12	1690.56	53.84
	2009	621.02	484.99	1895.00	58.44
	2010	703.60	556.49	2178.19	60.35
Labor of industry sector (Thousand person)	2006	2452.10	2765.86	12035.80	122.00
	2007	2624.39	3007.72	13074.00	123.30
	2008	2945.28	3454.37	14933.80	126.10
	2009	2943.18	3317.80	14360.20	120.00
	2010	3180.93	3596.90	15680.00	124.40
Industrial energy consumption (Million tons of coal equivalent)	2006	36.61	28.97	115.19	1.02
	2007	35.76	28.48	117.96	1.61
	2008	38.90	29.18	116.95	1.69
	2009	41.94	30.37	120.01	1.69
	2010	46.00	37.09	157.97	1.72
Total industrial output value	2006	373.90	337.36	1314.70	21.32

(Billion yuan)	2007	436.28	391.33	1538.20	26.82
	2008	492.88	436.87	1713.56	28.70
	2009	555.36	484.07	1871.20	32.32
	2010	644.26	547.58	2146.27	38.52
CO_2 emissions	2006	131.21	112.59	470.00	3.43
(Million tons)	2007	129.51	117.00	467.17	7.03
	2008	144.60	111.56	458.60	7.95
	2009	160.42	123.94	538.18	7.77
	2010	181.66	167.41	719.57	5.26

4.2 Results and analysis

During our ex-post analysis period of 2006-2010, China had not established a CO_2 emission permit trading scheme and thus, China's environmental regulations on industrial energy consumption intensity reduction and related carbon emission intensity reduction were implemented as command-and-control policy instruments for emission control. Therefore, the observed CO_2 emissions as well as the observed total industrial output value from industry sectors of China's 30 provincial level regions during 2006-2010 are taken as the base line (i.e., with environmental regulations and a command-and-control scheme) for estimating CO_2 emission abatement costs as well as CO_2 emission abatement cost savings from emission permit trading. Table 2 report the estimation results of each single year and five years' total of China's all 30 provinces.

Table 2 first shows that, during the entire ex-post analysis period, if there were no emission regulations on industrial CO_2 emissions, a maximum total industrial output value of 75080 billion yuan could be expected, which is 2.45% higher than the maximum total industrial output value with industrial CO_2 emission regulations. The difference between these two values is 1842 billion yuan which indicates the CO_2 emission opportunity abatement cost in China's industry sector during 2006-2010. This result implies that China's environmental regulations implemented on industrial carbon emission control reduced its total industrial output value by about 2.45% during 2006-2010.

Table 2 Estimation results

Evaluation indicators	2006	2007	2008	2009	2010	Total
Observed total industrial output value (Billion yuan)	11216.93	13088.41	14786.38	16660.83	19327.81	75080.37
Maximum total industrial output value without emission regulation (Billion yuan)	12013.16	13972.76	15791.21	17891.98	20680.89	80350.00
Maximum total industrial output value with emission regulation (Billion yuan)	11634.59	13593.04	15489.66	17455.50	20335.03	78507.82
Emission opportunity abatement cost (Billion yuan)	378.57	379.72	301.55	436.47	345.86	1842.18
Percentage of emission opportunity abatement cost over observed total industrial output value	3.37%	2.90%	2.04%	2.62%	1.79%	2.45%
Maximum total industrial output value with emission permit trading (Billion yuan)	11645.83	13630.36	15592.88	17577.66	20376.44	78823.18
Emission abatement cost saving from emission permit trading (Billion yuan)	11.24	37.32	103.22	122.16	41.42	315.36
Percentage of emission abatement cost saving over emission opportunity abatement cost	2.97%	9.83%	34.23%	27.99%	11.97%	17.12%
Potential CO_2 emission reduction from emission permit trading (Million tons)	-200.36	-150.59	-200.38	-93.16	-421.46	-1065.95
Observed CO_2 emissions (Million tons)	3936.30	3885.41	4338.06	4812.57	5449.88	22422.22
Percentage of potential CO_2 emission reduction over observed CO_2 emissions	-5.09%	-3.88%	-4.62%	-1.94%	-7.73%	-4.75%

Second, it can be found in Table 2 that, if CO_2 emission permits are tradable, i.e., these emission permits are allowed to be reallocated among different industry sectors in different provinces, a maximum total industrial output value of 78823 billion yuan is achievable. The difference between the maximum total industrial output value with emission permit trading and the maximum total industrial output value with emission regulation (but with no emission permit trading) indicates the emission abatement cost saving from emission permit trading, and this abatement cost saving in China's industry sector during 2006-2010 is 315 billion yuan, which accounts for 17.12% of emission opportunity abatement cost. This result implies that the establishing of CO_2 emission permit trading scheme in China's industry sector would help to recover the CO_2 emission opportunity abatement cost by about 17 percent during 2006-2010.

Last but not the least, Table 2 reports that additional 1065.95 million tons of CO_2 emission reductions could be realized in China's industry sector from emission permit trading, and this accounts for 4.75% of the total industrial CO_2 emissions during 2006-2010.

Figure 1 additionally illustrates the observed total industrial output value, the emission opportunity abatement cost, and the emission abatement cost saving from emission permit trading in each year of the ex-post analysis. Both the highest emission opportunity abatement cost and the highest emission abatement cost saving occurred in 2009; while 2008 and 2006 observed the lowest emission opportunity abatement cost and the lowest emission abatement cost saving, respectively.

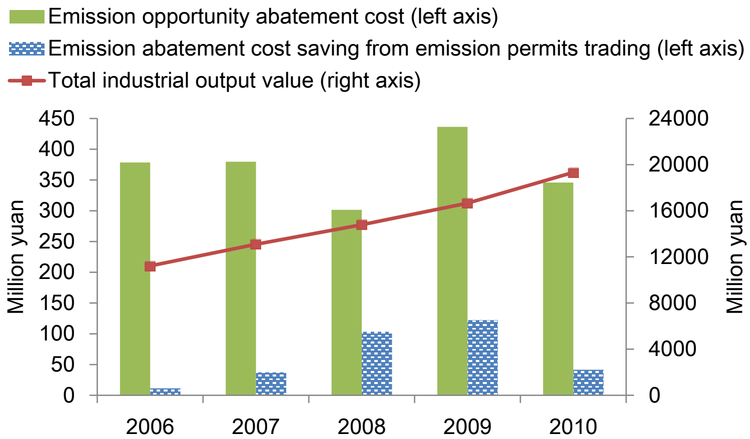
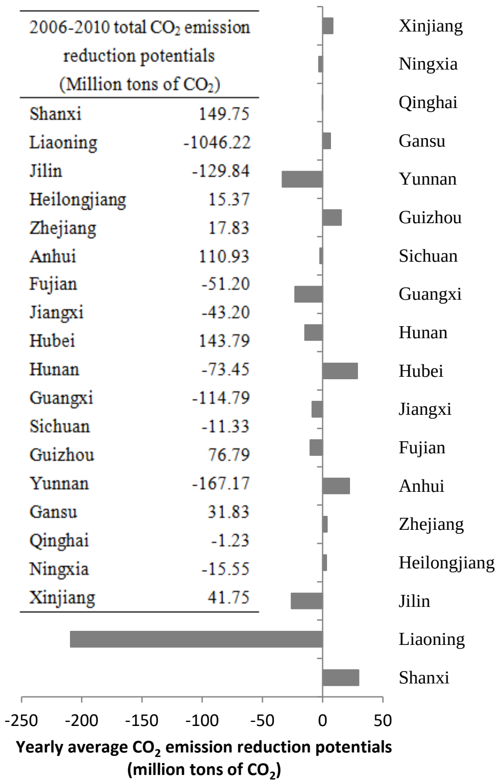


Figure 1 Abatement costs and abatement cost savings of China's industry sector



2006-2010 total CO_2 emission reduction potentials (Million tons of CO_2)	
Shanxi	149.75
Liaoning	-1046.22
Jilin	-129.84
Heilongjiang	15.37
Zhejiang	17.83
Anhui	110.93
Fujian	-51.20
Jiangxi	-43.20
Hubei	143.79
Hunan	-73.45
Guangxi	-114.79
Sichuan	-11.33
Guizhou	76.79
Yunnan	-167.17
Gansu	31.83
Qinghai	-1.23
Ningxia	-15.55
Xinjiang	41.75

Figure 2 Industrial CO_2 emission reduction potentials from emission permit trading

Figure 2 shows the CO_2 emission reduction potentials from emission permit trading for industry sectors of 18 Chinese provinces. The bar chart in Figure 2 is the yearly average reduction potential and the table beside is the 5 year's total reduction potential for each province. Negative value indicates CO_2 emission reduction and positive value means CO_2 emission increase after emission permit trading. Another 12 provinces show net zero CO_2 emission reduction potential during 2006-2010, thus they are omitted in Figure 2. It can be seen that, if the initial CO_2 emission allowances were allocated to each industry sector of each province according to their observed CO_2 emission, after emission permit trading, the industry sectors in Shanxi, Heilongjiang, Zhejiang, Anhui, Hubei, Guizhou, Gansu and Xinjiang would be buyers of CO_2 emission permits; while Liaoning, Jilin, Fujian, Jiangxi, Hunan, Guangxi, Sichuan, Yunnan, Qinghai, and Ningxia would be sellers.

To sum up, on the one hand, CO_2 emission permit trading would help China's industry sector to save emission reduction cost, and on the other hand it would help to release additional industrial CO_2 emission reduction potentials in China. Furthermore, all provinces that participated in the emission trading scheme would benefit from emission reduction opportunity cost recovery and/or extra emission reductions in their industry sectors. This provides a justification for establishing an industry CO_2 emission permit trading system in China. It also provides Chinese government a flexibility in the determination of abatement cost savings over different provinces to achieve further economic and social development goals.

5 Conclusions

This study utilized several DEA based models to estimate the CO_2 emission opportunity abatement cost and the potential cost saving effect from CO_2 emission permit trading in China's industry sector over the period of 2006-2010. Based on the calculations of maximum amount of total industrial output values with and without environmental regulations (i.e., energy conservation and associated carbon emission control), the emission opportunity abatement cost of each industry sector in China's 30 provinces is obtained. Then the CO_2 emission abatement cost saving from spatial trading of CO_2 emission permit is calculated which measures the abatement cost recovery from eliminating spatial regulatory rigidity on emission permit reallocation. The estimation results from an ex-post analysis indicate that in China's industry sector: (i) The CO_2 emission opportunity abatement cost was 1842 billion yuan (2.45% of total industrial output value); (ii) The emission abatement cost saving from emission permit trading would be 315 billion yuan (17.12% of total emission opportunity abatement cost); (iii) 1065.95 million tons of CO_2 emission reductions would be achieved from emission permit trading (4.75% of total industrial CO_2 emissions); (iv) if the initial CO_2 emission allowances were allocated according to the observed CO_2 emission and the emission permit trading scheme was implemented, the industry sectors in Shanxi, Heilongjiang, Zhejiang, Anhui, Hubei, Guizhou, Gansu and Xinjiang would be buyers of CO_2 emission permits; while Liaoning, Jilin, Fujian, Jiangxi, Hunan, Guangxi, Sichuan, Yunnan, Qinghai, and Ningxia would be sellers of CO_2 emission permits during our study period. The substantial CO_2 emission abatement cost recovery identified in this study provides one more justification for establishing a unified CO_2 emission permits trading system in China in 2017.

Acknowledgement

Ke Wang gratefully acknowledges the financial support from the National Natural Science Foundation of China (grant nos. 71471018, 71521002 and 71101011), and the Basic Scientific Research Foundation of BIT (grant no. 20152142008).

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