Potential Effect of Interprovincial Carbon Trading in China

Cheng Zhang, Dan Shi, Pengfei Li*

Taking provincial panel data of China as the sample, this paper simulates and analyzes the potential effect of carbon emissions trading in China under the condition of unconstrained and constrained respectively. The results are as follows. (1) As the theoretical basis of carbon trading, the shadow price of carbon dioxide is inclined to rise generally. The absolute gap among provinces and that among eight regions tend to expand, but the relative gap tends to narrow. (2) With the reduction of national carbon intensity to the greatest degree as the aim, carbon trading could reduce the carbon intensity by 20.06% under the condition of given national GDP. If the strict constraint of national GDP is relaxed, and the constraint of economic growth and environment conservation of each region is imposed, carbon trading could reduce the carbon intensity by 22.20%. (3) The current overall promotion process of carbon intensity in China has achieved the phased goal of the Copenhagen Conference commitment. The interprovincial carbon trading could strongly boost the improvement of carbon intensity, and the general requirements of Copenhagen Conference could be satisfied.

Keywords: carbon trading, shadow price, carbon intensity, Copenhagen Conference

1. Introduction

In the first year of the 13th Five-Year Plan of the national economy, the promotion of carbon intensity was barely satisfactory in the past stage, which basically satisfies the commitment of Copenhagen Conference, as well as the stage goal of 12th Five-Year Plan. However, the hardship can be imagined. The current achievement is benefited from the sustained slowdown in GDP growth, as well as the "sluice power limit" type of shock measures. Along with future recovery of economy and the increasingly formal measures

* Cheng Zhang (email: 15251777990@163.com), Associate Professor, School of Economics, Nanjing University of Finance and Economics, Postdoctoral Fellow in Institute of Industrial Economics, Chinese Academy of Social Sciences; Dan Shi, Ph.D.Supervisor of Institute of Industrial Economics, Chinese Academy of Social Sciences; Pengfei Li, Associate Research Fellow, Institute of Industrial Economics, Chinese Academy of Social Sciences. Fund Project: A Major Bidding Project of National Social Science Fund "The Interconnection and Interoperability Strategy Research of Power between China and Neighboring Countries" (13&ZD168); China's Postdoctoral Science Fund "Duality of Energy and Potential Effectiveness of China's Carbon Emissions Trading" (2016T90166). The authors are grateful for the support of 333-research funding and the green blue project-training program in Jiangsu.

of energy saving and emission reduction, achieving the commitment of the Copenhagen Conference and the goal of the next national economic planning would inevitably face greater challenges, which forces China to implement and improve market-based measures of emission reduction as soon as possible, especially the emission permits trade of carbon characterized by quantity control adopted by many countries in the world.

In recent years, Chinese government has paid great attention to the construction of domestic carbon trading market. The third Plenary Session of the 18th CPC Central Committee proposed the innovative guideline of "enabling the market to play a decisive role in the resource allocation of and the government to better play its role", which straightens out the relationship between the government and market and provides the theoretical support and policy basis for the further implementation of market-based carbon trading policy. In practice, China has made some breakthroughs at the regional and industrial levels since 2013. At the regional level, Beijing, Shanghai and 5 provinces including Guangdong are carrying out the pilot work of carbon trading, and actively exploring the schemes and models of the regional carbon trading market. At the industrial level, the National Development and Reform Commission officially launched a voluntary emission reduction project that publishes accounting and reporting guidelines, which makes the greenhouse gas statistical accounting system more perfect, as well as ensuring the smooth development of greenhouse gas emission reduction trade in 10 industries. According to *The Working Plan for Greenhouse Gas Emissions Control during the 13th Five-Year Plan* issued by the State Council in November 2016, China would open the national carbon trading market in 2018.

Now the question is what kind of reform bonus could be got from building the national carbon trading market? The existing literature uses a variety of methods to simulate and analyze the relevant effects of China's implementation of national carbon trading mechanism, and generally recognizes the significant effect of carbon trading mechanism in promoting energy saving and reducing GDP loss (Zhang *et al*., 2009; Cui *et al*., 2013; Hübler *et al*., 2014; Cui *et al*., 2014; Sun *et al*., 2014; Yuan *et al*., 2016). For example, Zhang *et al*. (2009) use the CGE model and computational model to study the comprehensive impact of carbon trading and carbon tax mechanism on industries in China, and find that if the carbon emissions had been reduced by 10% in 2006, the loss of GDP could be 0.23% with the carbon tax mechanism while it could be reduced to 0.17% with the carbon trading mechanism. Cui *et al*. (2013) construct an inter-provincial carbon trading model and study the cost saving effect of carbon trading mechanism in the process of realizing the target of reducing emission in each province, and find that carbon trading could cost about 23.44% less than carbon free transaction, and carbon trading market would have different cost saving effects on the participating provinces. Based on the function of emission reduction cost, Cui *et al*. (2014) simulate the effect of cost saving of implementing carbon trading pilot and national carbon trading, and get the conclusion that they could save 4.5% and

23.67% of total emission reduction cost respectively. Under the background of carbon trading, Sun *et al*. (2014) analyze the direct and indirect effects of carbon price on macro economy, energy consumption and carbon emission reduction, and find that carbon trading can effectively promote carbon emission reduction in the sectors of coal, heavy industry, electric power and light industry while it has no obvious effect on transportation and construction. Based on the model of CGE, Hübler *et al*. (2014) find that if the commitments of the Copenhagen Conference were to be achieved, much welfare would be lost, and the GDP loss could be controlled to 1% under the condition of carbon trading. Based on the multi-regional general dynamic equilibrium model, Wu *et al*. (2014) find that the total carbon emission control and transaction mechanism is more applicable to the current China in the condition of incomplete information. With the strengthening of emission reduction efforts in the future, the carbon tax policy should be taken into consideration. Yuan *et al*. (2016) construct a multi-region CGE model that contains the carbon emission module to simulate and analyze the relative effects of carbon trading in various initial distribution models, and the results give approval to the potential effect of carbon emission trading across regions.

Although literature has preliminarily estimated the effects of carbon trading from different perspectives, most of the research is based on the cost function of emission reduction, which takes the carbon dioxide as a "bad output", and it takes the corresponding economic cost to reduce the cost. In fact, the carbon dioxide is a kind of emission, not a kind of pollutant. At the current technical level, it is difficult to reduce the emission of carbon dioxide through the terminal equipment just as the sulfur dioxide and chemical oxygen. At present, carbon dioxide emission reduction mainly depends on improving energy efficiency, reducing the ratio of high carbon energy, optimizing industrial structure, increasing production efficiency and reducing output, which is related to production to a greater extent. Moreover, carbon dioxide and fossil energy are two sides of a coin, and energy is one of the most important factors supporting economic growth. At the same time, energy, capital, labor and other factors would have the corresponding substitution effect (Smyth *et al*., 2011; Sun *et al*., 2012; Steinbuks and Narayanan, 2015), which affects the economic output. Therefore, in order to evaluate the potential effects of carbon trading, it is more appropriate to analyze the impact of carbon dioxide emission on economic output from the perspective of production function instead of the cost function. As early as 1991, Hueting pointed out that the shadow price of environmental pollution is the cornerstone of environmental public policy and the accounting of environmental growth (Hueting, 1991), which could be applied to the cost-benefit analysis of environment policies (Kuosmanen and Kortelainen, 2007). If the price of carbon dioxide in the economies were equal, then the economic effectiveness would be achieved (Coggins and Swinton, 1996), which is the expected result of the carbon trading.

In order to promote the relevant theoretical research on carbon trading, and provide possible help for government to clarify the potential effects of carbon trading and to formulate relevant policies, this paper uses the provincial panel data to estimate the shadow price of interprovincial carbon dioxide. Based on the shadow price, this paper analyzes the potential effect of provincial carbon trading on the emission of carbon dioxide, economic growth and carbon intensity under the two conditions, which is conductive to judge whether it could be possible to push forward the successful completion of Copenhagen Conference commitments. The main value of the study is that this paper focuses on the characteristics of factor of carbon dioxide and conducts research from the perspective of production function. The other value is that this paper analyzes the potential effect of carbon trading in the condition with constraints, as well as without national conditions.

2. Research Method

This paper first uses the stochastic frontier technology to estimate the shadow price of carbon dioxide among provinces. If there is a large difference in the shadow price of carbon dioxide, the counter factual nonlinear programming technology is used to simulate and analyze the interprovincial carbon emission trading, i.e., what kind of potential effect can be brought if certain amounts of carbon emission could be sold from low efficiency provinces to high efficiency provinces.

2.1. Estimation of Carbon Dioxide Shadow Price Based on the Stochastic Frontier Technology

First of all, we need to estimate to what extent that carbon dioxide could promote economic growth. In specific research, the reason why we use the method of stochastic frontier analysis (SFA) is that this method could not only decompose the technical efficiency from productivity, but also could control the disturbance caused by the random error term, which would more accurately depict the nonlinear relationship between carbon dioxide and output. Based on the model of Battese and Coelli (1995), the SFA function is as follows:

$$Y_{it} = \exp\left(X_{it}\,\beta + V_{it} - U_{it}\right) \tag{1}$$

In equation (1), i and t represent the cross section and time respectively. Y and X represent output and input respectively. β is the solve-for parameter and $x_{ij}\beta$ is the deterministic frontier output of the output front in the decision unit, which represents the deterministic maximum output under the existing technical condition. V is a random deviation term that satisfies the condition of $iid\ N(0,\sigma_v^2)$, which measures the random effect of luck factors on output. U is the technical inefficiency that satisfied the condition of *iid* $|N(0,\sigma_{it}^2)|$, which represents the loss of output caused by the differences in the level of internal management. The inefficiency model could be expressed as:

$$U_{it} = Z_{it}\ \delta\ + W_{it} \tag{2}$$

Among them, Z represents the explanatory variable of technical inefficiency and δ is the solve-for parameter. W is the random error term that satisfies the $N^{+}(0,\sigma_U^2)$. The truncated point is $-Z_{it}\ \delta$, and $W_{it} \geqslant -Z_{it}\ \delta$ is satisfied. If the coefficient of explanatory variable Z is significantly positive, it means the introduction of this variable would significantly increase the level of technical inefficiency, and vice versa.

In the estimation of stochastic frontier production function, we use the function that contains capital (K), effective labor (L),[1] carbon dioxide (C) and technical level (T). In order to examine the marginal output and elasticity of factor input, the production function is set as a transcendental logarithm form:[2]

$$\text{Log}Y_{it}=\beta_0+\beta_1\text{Log}K_{it}+\beta_2\text{Log}L_{it}+\beta_3\text{Log}C_{it}+\beta_4\text{Log}K_{it}^2+\beta_5\text{Log}L_{it}^2+\beta_6\text{Log}C_{it}^2+\beta_7\text{Log}K_{it}\text{Log}L_{it}+\beta_8\text{Log}K_{it}\text{Log}C_{it}+\beta_9\text{Log}L_{it}\text{Log}C_{it}+\beta_{10}T_t+\beta_{11}T_t^2+\beta_{12}T_t\text{Log}K_{it}+\beta_{13}T_t\text{Log}L_{it}+\beta_{14}T_t\text{Log}C_{it}+V_{it}-U_{it} \tag{3}$$

In equation (3), β is the solve-for parameter. Based on the results of model estimation, the shadow price of carbon dioxide in each province($CDSP$) could be obtained:

$$CDSP_{it} = \left[\left(\beta_3 + 2\beta_6 LogC_{it} + \beta_8 LogK_{it} + \beta_9 LogL_{it} + \beta_{14}T_t\right)\cdot Y_{it}\right]/C_{it} \tag{4}$$

2.2. Potential Effects Evaluation of Interprovincial Carbon Trading with Counterfactual Nonlinear Programming Technique

Since Fogel (1964) used the method of counterfactual analysis (CFA) in 1964, this method has been widely used by scholars to analyze the following two types. First, for an event or thing that exist in history, assume it did not exist, and estimate the result of this assumption on economic operation. Second, for an event or a thing that did not exist in history, assume it did exist, and estimate the result on economic operation. The

[1] It is expressed by the product of labor force and human capital level.

[2] In the selection of specific model forms, the test of γ could be used to judge whether the stochastic frontier production function is more effective than the ordinary least square (OLS). Moreover, by constructing the likelihood ratio statistics, this paper chooses the specific form of transcendental logarithmic production function. Limited to space, detailed specific methods is no longer described, and the relevant steps can be seen in the literature of Xie (2006).

type of analysis in this paper is based on the latter assumption, which means assuming that national carbon trading is existed. By combining the counterfactual analysis and nonlinear programming technique, this paper simulates and analyzes the potential results of interprovincial transaction of carbon dioxide.[1] In the specific analysis, this paper uses the two scenarios of counterfactual nonlinear simulation.

Scenario A: Assuming the capital stock, quantity of labor force, level of human capital, technology and the degree of technical inefficiency are constant, carbon dioxide would be allowed to trade between provinces, and the national carbon intensity is minimized on the premise of keeping the total amount of GDP unchanged. Based on the above thinking, we consider the following counterfactual nonlinear programming:

$$\begin{aligned}
&\text{Min } CI_t \\
&\text{s.t. } \sum_{i=1}^{n} = Y_t \\
&Y_{it} = F_i[K_{it}, L_{it}, C_{it}, T_{it}, U_{it}] \qquad (i=1,2,\ldots,n) \\
&\sum_{i=1}^{n} C_{it} = C_t \\
&CI_t = C_t / Y_t \\
&Y_t = \overline{Y_t};\ K_{it} = \overline{K_t};\ L_{it} = \overline{L_t};\ T_{it} = \overline{T_t};\ U_{it} = \overline{U_t} \\
&C_{it} \geqslant 0; Y_{it} \geqslant 0 (\forall\ i, t)
\end{aligned} \tag{5}$$

In equation (5), it is assumed that there are n provinces providing output (Y) with the input factors of capital (K), effective labor (L) and carbon dioxide (C) with the established technical level (T) and technical inefficiency (U), and the various inputs are divided into two subsets of free disposal and non-free disposal. In the mathematical programming, they are treated differently, which makes the change of free disposal input and the expansion of output while keeping the non-free disposal input unchanged. Among them, carbon dioxide emission is the freely disposal variable, and other inputs are non-free disposal variables. The "—" above each variable represents the actual level of each year.

Scenario B: Assuming the capital stock, quantity of labor force, level of human capital, technology and the degree of technical inefficiency are constant, carbon dioxide would be allowed to trade between provinces. However, carbon dioxide emissions and real economic growth rate in each province are subjected to certain constraints. Based on this, the corresponding minimization level of national carbon intensity is obtained. This thinking is embodied in the following counterfactual

[1] If the shadow price of carbon dioxide in various provinces of China is inconsistent, it would indicate that the contribution of last unit of carbon dioxide emissions is different in the whole country. The transmit of carbon dioxide emission right from provinces with lower efficiency to higher efficiency could enhance China's overall level of output.

nonlinear programming:

$$
\begin{aligned}
&\text{Min } CI_t \\
&\text{s.t.} \quad \sum_{i=1}^{n} Y_{it}=Y_t \\
&Y_{it}=F_i[K_{it}, L_{it}, C_{it}, T_{it}, U_{it}] \qquad (i=1,2,\ldots,n) \\
&\sum_{i=1}^{n} C_{it}=C_t \\
&CI_t=C_t/Y_t \\
&K_{it}=\overline{K_{it}};\ L_{it}=\overline{L_{it}};\ T_{it}=\overline{T_{it}};\ U_{it}=\overline{U_{it}} \\
&C_{it}\leqslant \psi_{it}C_{i,t-1};Y_{it}\geqslant \theta_{it}Y_{i,t-1};C_{it}\geqslant 0;Y_{it}\geqslant 0(\forall\, i, t)
\end{aligned}
\tag{6}
$$

In equation (6), ψ is the upper limit ratio coefficient of carbon dioxide emission, which is used to restrain the highest carbon dioxide emission in each province; θ is the lower limit ratio coefficient of GDP growth, which is used to restrain the lowest GDP growth in each province.

3. Variable and Data Description

In the empirical analysis, the variables involved in the production function model are as follows. (1) Output (Y): the actual regional GDP with the price of 2000 is selected as output. (2) Effective labor input (L): the number of employees in the whole society at the end of the year multiplied by the level of human capital is regarded as input. Among the variables, the level of human capital is calculated according to the degree of education and rate of return of education (Barro and Lee, 2013; Psacharopoulos, 1994). In the specific calculation, illiteracy, primary school, junior high school, high school, junior college education, undergraduate, graduate student or above is assigned with 0, 6, 9, 12, 15, 16 and 19. (3) Capital input (K): the capital stock is calculated according to the perpetual inventory method referring to Dan (2008). (4) The input of CO_2 (C): the emission of CO_2 is calculated through various energy consumption, such as coal, coke, crude oil, gasoline, gas, diesel, fuel oil and natural gas. Based on this calculation, the CO_2 emission coefficients are 1.958, 2.8456, 3.0513, 2.9251, 3.052, 3.0976, 3.1851 and 21.605. (5) Technological progress (T): if the technological progress is added, the time span 1~18 could be used.

The variables involved in the technical inefficiency model are as follows. (1) Government decentralization ($G\&M$): in order to reflect the core idea of "enabling the market to play a decisive role in resource allocation and the government to better play its role" in the third Plenary Session of the 18th CPC Central Committee, the relationship index between government and market provided by Fan (2011) is used. Since the index only includes the data from 1997 to 2009, this paper supplements to 2012 according to the VAR model. (2) The ratio of industrial service industry

(*IND*): it is measured by the ratio of industrial added value to the value added of the third industries. (3) Proportion of foreign direct investment (*FDI*): it is measured by the ratio of FDI capital stock to GDP. The formula that calculates the stock of FDI is $ZFDI_{it}=(1-\delta)ZFDI_{i,t-1}+fdi_{it}$. In the formula, *ZFDI* represents the capital stock of FDI, *fdi* represents the new FDI investment, and δ is depreciation rate with the value of 0.096. The initial capital stock is selected with value of the year of 1990. The formula is $ZFDI_{i,1990}=fdi_{i,1990}/(g+\delta)$, and g represents the average annual growth rate from 1990 to 2000. (4) R&D input intensity (*R&D*): it is measured by the total expenditure of research and development institutions in each province, and taking into account the lagging effect of scientific research investment's impact, this paper takes a lag phase in the model regression.

This paper selects the panel data of 29 provinces in China from 1995 to 2012. Tibet, Hongkong, Macao and Taiwan are not considered in the sample, and Chongqing is taken into Sichuan. The data is compiled and calculated according to *Statistical Yearbook of China*, *Yearbook of China's Population and Employment Statistics*, *Yearbook of China's Scientific and Technological Statistics*, and *Statistical Yearbook* of provinces. In order to reduce the impact of price factor, all relevant prices are adjusted to the price of 2000. Descriptive statistics of related variables are shown in Table 1.

Table 1. Descriptive Statistics of Related Variables

Variable	Mean	Standard deviation	Minimum value	Maximum value	Observation number
GDP	6110.35	6505.77	173.27	42872.29	522
Carbon dioxide	24267.54	20139.02	562.36	122974.63	522
Capital stock	12236.63	13251.12	357.99	84353.71	522
Effective labor input	19291.25	13824.89	1211.25	68626.99	522
Technological progress (period)	9.50	5.19	1.00	18.00	522
Government decentralization	7.63	1.53	3.75	11.55	522
Ratio of industrial service industry	1.09	0.30	0.24	1.81	522
Proportion of foreign direct investment	0.16	0.14	0.01	0.73	522
R&D intensity	0.0118	0.0098	0.0017	0.0582	522

In the analysis, the provinces in China are divided into three regions: East, Central, and West. Moreover, according to the development strategy of China Development Research Center of the State Council, 29 provinces are further divided into eight regions: northeast region (Heilongjiang, Jilin, Liaoning), northern coastal region (Beijing, Hebei, Shandong, Tianjin), eastern coastal region (Jiangsu, Shanghai, Zhejiang), southern coastal region (Fujian, Guangdong, Hainan), middle reaches of the Yellow River (Henan, Inner Mongolia, Shanxi, Shaanxi), middle reaches of Yangtze

River (Anhui, Hubei, Hunan, Jiangxi), southwest region (Guangxi, Guizhou, Sichuan, Yunnan) and northwest region (Gansu, Ningxia, Qinghai, Xinjiang).

4. Estimation and Analysis of Shadow Price of Carbon Dioxide

4.1. Estimation Results and Analysis of Stochastic Frontier Models

It is necessary to determine the applicability and the specific form of stochastic frontier production function before using the model to estimate the shadow price of carbon dioxide. According to the results of likelihood ratio test, the function is applicable, and the optimal form is shown in Table 2. The transcendental logarithmic function form that includes the level of technological progress and its quadratic term is more appropriate. The specific test results would not be provided due to limited to the space. It can be seen that most of the core independent variables are significant at the level of 10%, and the value of γ is 0.9975 with the significant level of 1%, which indicates that the technology inefficiency is universal. The error of frontier production function is mainly caused by technical inefficiency, which further indicates that it is necessary and effective to conduct an analysis of stochastic frontier production function.

Table 2. Estimation Results of Stochastic Frontier Production Function Model

Explanatory variable	Coefficient	Value of Z	Explanatory variable	Coefficient	Value of Z
LnK	0.8082^{***}	(3.8829)	T×LnL	-0.0028^{**}	(–2.4828)
LnL	1.0171^{***}	(3.8825)	T×LnC	-0.0134^{*}	(–4.6457)
LnC	-0.4050^{***}	(–3.4119)	C_1	0.1167^{***}	(0.5875)
LnK×LnL	0.0058	(0.8813)	Model of inefficiency technology		
LnK×LnC	0.1220^{***}	(4.9824)	C_2	1.9224^{***}	(5.5952)
LnL×LnC	$-0.0324^{\#}$	(–1.4475)	*G&M*	-0.0657^{***}	(–9.9359)
LnK×LnK	-0.1014^{***}	(–4.1869)	*IND*	2.3572^{***}	(4.2397)
LnL×LnL	-0.0363^{*}	(–1.7730)	*FDI*	-3.2458^{***}	(–4.8716)
LnC×LnC	–0.0097	(–0.6800)	*R&D*	-4.0124^{***}	(–6.7841)
T	$0.0575^{\#}$	(1.6130)	σ^2	0.1284^{***}	(6.1874)
T×T	0.0003	(1.3547)	γ	0.9975^{***}	(15.8216)
T×LnK	0.0175^{***}	(4.1636)	*Log-likelihood*	831.6730	

Note: The value in the brackets is that of Z; ***, **, * and $^{\#}$ represent the significant level at 1%, 5%, 10% and 15% respectively. Ln means the logarithm based on e.

In the technical inefficiency model, the effect of the four control variables is significant at the level of 1% at least. The coefficient of government decentralization, proportion of foreign direct investment and R&D intensity is negative, which indicates that the height adjustment of these three variables would bring negative influence on technical inefficiency, and this also indicates that the level of technical efficiency would be improved. The coefficient of ratio of industrial service industry is positive, which indicates the moderate increase in the ratio of service industry is beneficial to the improvement of technical efficiency. As a result of China's current industrial policy, the proportion of service industry is being constantly improved. China should

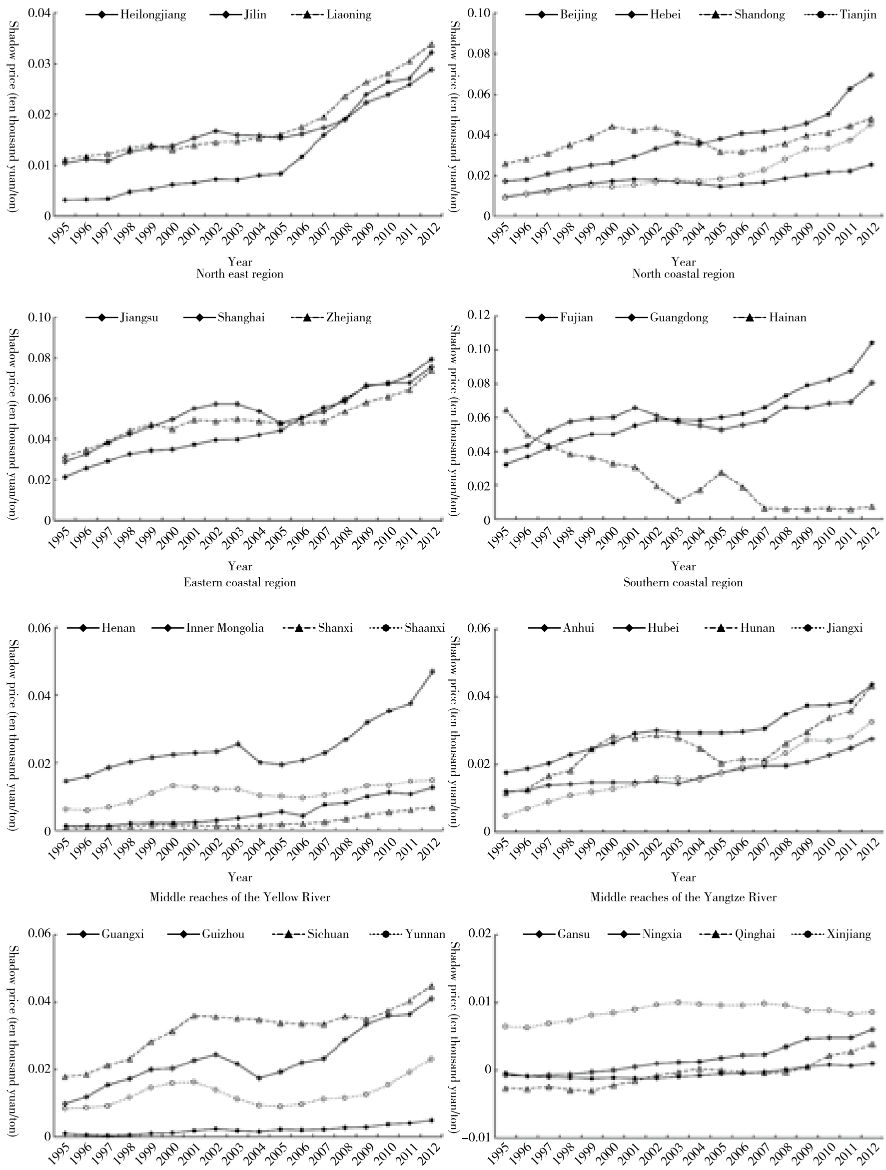

Figure 1. The Shadow Price of Carbon Dioxide in Different Provinces in China over the Years

strive for the growth of service industry to nurture the manufacturing industry, which achieves a win-win situation in the industry and services sector (Huang *et al*., 2013; Zhang *et al*., 2015).

4.2. Spatial and Temporal Characteristics of Carbon Dioxide Shadow Price in Each Province in China

Based on the estimated results of stochastic frontier model, we calculate the shadow price of carbon dioxide in China's each province during the sample period. The relative results shown in Figure 1 indicate the asymmetric negative correlation between carbon dioxide emission and shadow price of carbon dioxide emissions. According to the principle of diminishing marginal returns, the shadow price tends to decrease along with the increase of carbon dioxide emissions. But the shadow price of either side of any emissions is asymmetrical, which indicates the shadow price of a unit of carbon dioxide emission reduction is higher than that of a unit of carbon dioxide emission augment.

For the shadow price of carbon dioxide, the general trend shows a typically decreasing from east to west. For the eight regions, the average shadow price of carbon dioxide in eastern coastal area was 762 yuan per ton in 2012, which was the highest in the whole country. The shadow price of carbon dioxide in the northwest region was only 49 yuan per ton, which was the lowest. As for provinces, the shadow prices of carbon dioxide in Guangdong (1040 yuan per ton), Fujian (807 yuan per ton), Shanghai (795 yuan per ton) were the top in the country while the shadow prices in Ningxia (10 yuan per ton), Qinghai (38 yuan per ton) and Guizhou (49 yuan per ton) were at the lower end.

The shadow price of carbon dioxide showed an upward trend in the sample time span, and the increasing of price in most provinces declined from 2002 to 2005. With government paying more attention to environmental problems during 1995 to 2002, a large number of small coal mines, small thermal power plants and printing plants were closed. At the same time, with the introduction of modern enterprise system and the market-oriented reform of coal and other resources, as well as the rapid development of non-state-owned industry, the allocation efficiency of energy in regional industry has been effectively improved (Chen, 2009), which contributes to the upward trend of the shadow price of carbon dioxide during the period. But after 2003, heavy industries such as oil, building materials, mining, metallurgy and other heavy industries have developed rapidly in order to support the expansion of infrastructure such as real estate, automobile, and railways, highways airports (Kuang and Peng, 2012), which makes the energy consumption increase rapidly in the next few year and even far higher than the growth of capital and labor. This inevitably contributes to hindered growth and even slight decrease of shadow price of carbon dioxide. Since 2006, with the renewed emphasis on energy and environmental protection and refinement index issuing in the 11th Five-Year Plan and other documents, the substitution effect of capital and labor on energy has gradually increased, and the corresponding shadow price of carbon dioxide has continued to rise. Due to the impact of the international financial crisis in 2008, the growth of carbon dioxide shadow price was once again been slightly hindered, in the two years the growth increased again.

The evolution pattern of shadow price of Hainan's carbon dioxide in the period years has declined in general from the leading edge at the beginning to the backward position at the end of the term. The inter-annual change is closely related to the adjustment of Hainan's industrial structure. From 1995 to 2000, the proportion of second industry in Hainan has been hovering around 20%, and the annual average of 43.5% of GDP is made up of the third industry, which results in less energy consumption and low CO2 emission in Hainan, with the highest carbon productivity from 1995 to 2000 as the evidence. From 2001, the proportion of second industry has tended to rise from 19.8% in 2000 to 29.0% in 2006 while that of third industry has decreased from 43.8% in 2000 to 40.7% in 2006. The rise of high carbon industry and relative weakening of Hainan's output capacity led to the deviation of Hainan from the frontier efficiency, and the efficiency was reduced to the bottom of 2007 (0.5201). However, the proportion of third industry has been raised from 40.7% in 2006 to 46.9% in 2012. Moreover, the proportion of the third industry with high-energy consumption has been significantly reduced, and that of finance and insurance and real estate industry with low-energy consumption has been raised rapidly. The upgrading proportion of third industry and the optimization of internal structure also lead Hainan's super efficiency to rebound since 2008 and increase to 0.6625 in 2012.

In addition, from the perspective of convergence, the absolute gap between provinces and regions has been expanding while the relative gap has been shrinking. The provincial standard deviation increased from 0.0151 in 1995 to 0.0293 in 2012 and the coefficient of variation decreased from 1.0717 in 1995 to 0.7906 in 2012. The regional standard deviation increased from 0.0142 to 0.0242 in 2012 and the coefficient of variation decreased from 0.9601 in 1995 to 0.6156 in 2012.

5. Analysis of Simulation Results of Interprovincial Carbon Trading

5.1. Potential Effect of Carbon Trading in the Unconstrained National Conditions

As Coggins and Swinton (1996) pointed out that there is a large difference in the shadow price of carbon dioxide in each economy, which provides the basic premise for the carbon trading between economies. If the carbon dioxide emission rights would be transferred from the economy with low shadow price to the economy with high shadow price, the overall economy would be further improved. Therefore, on the basis of the assumption that the capital stock, level of human capital, quantity of labor force, technology level and technology inefficiency are constant, and the GDP growth rate and carbon dioxide emission in each province have no special constraint, this paper simulates and analyzes the potential effect of CO_2 emission and carbon emission intensity in the scenario A that the total amount of GDP in the country is unchanged. The relative results are shown in Table 3.

It can be seen that in 2012, the total amount of carbon dioxide emission is more than 12 billion tons. The interprovincial transaction of carbon dioxide emission rights could reduce the carbon dioxide emissions by 2 billion tons with the reducing rate of 20.06%. From the perspective of eight regions, the carbon dioxide emission in eastern coastal areas and southern coastal areas increased from 511 million yuan and 319 million yuan to 783 million yuan and 598 million yuan respectively, which leads to the average GDP increase by 166 billion yuan and 201 billion yuan. As for the other six regions, carbon dioxide emissions should be reduced in varying degrees, especially in the middle reaches of the Yellow River, the reduction of more than 88 billion yuan of average GDP could lead to the reduction of more than 407 million tons of average CO_2 emission.

From the perspective of carbon intensity index, the original level of the whole country is 2.15 tons per 10 thousand yuan. The overall level of national carbon intensity is 2.6 tons per 10 thousand yuan in scenario A through the interprovincial transaction of carbon dioxide emission right, which is 20.06% lower than the original level. Among them, the carbon intensity in eastern coastal region and southern coastal region has increased by 43.51% and 68.91% respectively. However, the other six regions have seen reduction in various degrees with 81.82% in northwest region, 57.20% in middle reaches of the Yellow River, 34.34% in southwest region, 32.62% in northeast region, 22.61% in the middle reaches of the Yangtze River and 18.45% in northern coastal region. It can be found that if the shadow price of carbon dioxide is adjusted to the same level, the rank of carbon intensity in each province has been reversed to a great extent, which shows a decline from west to East. The reason is that capital and labor force is concentrated in the eastern provinces. Although the technology and technical efficiency of eastern provinces is higher than that in the central and western provinces, overly concentrated capital and labor would inevitably bring a relatively low level of shadow price of capital and labor force, which leads to the lower output efficiency of capital and labor force and the higher carbon intensity in eastern region.

Through the implementation of inter-provincial carbon trading, the original differential shadow price could be adjusted to a unified level of 504 yuan per ton, which contributes to the provincial equalization of marginal carbon dioxide output.

In general, the right of carbon dioxide emission right of six regions in northwest area has been sold to the eastern coastal areas and southern coastal areas. However, there are some differences in each area, which could be summed up into three points. (1) Northeast region, middle reaches of the Yellow River, middle reaches of the Yangtze River, the southwest and northwest regions need to sell carbon dioxide emission rights in varying degrees. The northern coastal areas generally need to sell carbon dioxide emission rights, and Beijing needs to buy the right to achieve higher economic output. Provinces in the eastern coastal area also need to buy the right, and the southern coastal areas need to buy the right in general, but Hainan needs to sell carbon dioxide emission right. (2) The greater the gap between shadow price of original carbon dioxide and unified level after carbon trading in each province, the relatively larger the quantity of carbon dioxide emission to be adjusted. (3) In addition to the shadow price of carbon dioxide, the specific adjustment of carbon dioxide is also affected by the economic size.

5.2. Potential Effect of Carbon Trading in the Constrained National Condition

The premise of scenario A is that certain amount of carbon emission rights are sold from the low efficiency province to high efficiency province, and the provinces with high efficiency could create higher economic output, which makes part of new economic output to compensate for the output losses in inefficient provinces. This contributes to the goal of effectively reducing CO_2 emission and carbon intensity with the overall economic output remaining unchanged. But the scenario cannot be put into practical operation in the real economy. If the emission rights were simply transferred to the developed areas, the developed area with high efficiency would become the production machines, which undoubtedly leads to large amount of waste water, sulfur dioxide, solid waste and other pollutants, as well as to the further deteriorated ecological environment. At the same time, the underdeveloped areas with low efficiency could obtain the corresponding economic compensation without taking additional pollution emissions. On the surface, it seems to be harmless. However, it may lead to the path dependence of the underdeveloped areas, as well as missing the rapid development opportunities of economic growth, which would not be conducive to the further development of underdeveloped areas. Therefore, in the actual operation, it is necessary to take the national condition into consideration. It should be clear that only by taking the economic growth of underdeveloped areas and environmental capacity of developed regions into consideration could the economic growth and environmental protection be balanced. Based on the data of 2012, this paper simulates the scenario with the constrained national condition of assuming capital stock, labor force, human capital, technology level, technology inefficiency unchanged and the CO_2 emission in each province should be lower than the actual level. At the same time, the real economic growth rate in eastern, central and western region could not be lower than 7%, 7.5% and 8%. With maximizing the carbon intensity reduction as the goal (Scenario B), this paper simulates the potential effect of interprovincial transaction of CO_2 emission rights.

The related results in Table 3 indicate that the total amount of carbon dioxide emission reduced to more than 9 billion tons with the double restriction of economic growth and environmental protection, which decreased by 24.32% compared with the original condition. The total amount of GDP was reduced to 37 trillion yuan with the decreasing rate of 2.71% while the carbon intensity reduced to 2.53 tons per 10 thousand yuan with the decreasing rate of 22.20%. The adjustment direction of each province in China is consistent with the overall trend of whole nation. Comparatively speaking, the average provincial reduction rates of carbon dioxide and carbon intensity in Northwest China are in the leading level in the whole country while those in the eastern coastal region are the lowest. As for the shadow price of carbon dioxide, the level of whole country raised to 489 yuan per ton, which increased by 33.2%, of which the improvement in the northwest region was the most obvious with the increasing rate of 246.94%. The improvement of eastern coastal region is relatively minimal with the increasing rate of 8.92%. Although the GDP in different provinces has been reduced in different degrees in Scenario B, the carbon intensity has been greatly improved. In the simulation scenario B of the carbon trading, if the carbon intensity of China as a whole could be minimized under the dual constraints of economic growth and environmental capacity, whether the economic growth or the environmental capacity plays the practical role of a constraint depends on the specific value of the GDP and carbon dioxide elasticity. If the elasticity is less than 1, one percent decreasing of CO_2 means one percent decreasing of GDP. With the continuous reduction of carbon dioxide, the corresponding carbon intensity shows a trend of improvement, and the actual constraint is the minimum growth limit of GDP. On the other hand, if the elasticity is greater than 1, the corresponding carbon intensity shows an improvement trend with increasing of carbon dioxide emission, and the actual constraint is the maximum limit of environmental capacity. The value of elasticity in scenario B is less than 1, which indicates that the carbon dioxide emission shows an improvement trend with the continuous reduction of carbon dioxide emission, and the minimum grouth limit of GDP plays a practical constraint role. Therefore, with the reduction of carbon dioxide emission, the overall carbon intensity shows a significant improvement trend although GDP shows the declining trend.

In scenario B, it is important to note that the shadow price of CO_2 has not been adjusted to the level of unified level as in scenario A when the interprovincial carbon trading is implemented. In scenario A, the shadow price of CO_2 is adjusted to 504 yuan per ton in each province in the condition of carbon trading without the constraint of economic growth and environmental capacity. However in scenario B, carbon dioxide emissions of each province could only be adjusted in the strict constraint of economic growth and environmental capacity, which leads to the rising trend of shadow price of CO_2. The gap among provinces is clear in scenario B.

Based on the solemn commitment made by Chinese government at the Copenhagen Conference to reduce carbon intensity by 40% to 45%, this paper estimates the current emission reduction. The calculation results show that the total carbon intensity of China's total provinces in 2012 was 3.2512 tons per ten thousand yuan, which was 26.73% lower than that in 2005. If China were to reduce the CO_2 emission by 20% in 2020, the carbon intensity would be reduced by 3.62% every year, which leads to the accumulative total reduction of 22.76%. It can be seen that the process of promoting commitment of Copenhagen Conference is smooth, which shows the responsibility and international power in fulfilling its international commitments. If the interprovincial transaction of carbon emission were introduced, the carbon intensity would be reduced to 2.5991 tons per ten thousand yuan and 2.5293 tons pen ten thousand yuan respecitively in scenario A and scenario B, which could lower 41.43% and 43% respectively than that in 2005. The commitment could be fully completed at Copenhagen Conference.

Table 3. Potential Effects of Interprovincial Carbon Trading in China in the Two Scenarios

		Original condition			Unconstrained condition (Scenario A)			Constrained condition (Scenario B)		
		GDP	Carbon dioxide	Shadow price	GDP	Carbon dioxide	Shadow price	GDP	Carbon dioxide	Shadow price
Northeast region	Heilongjiang	11717.41	39380.49	0.0288	11105.64	23162.70	0.0504	11451.10	31197.41	0.0369
	Jilin	7709.72	29042.18	0.0322	7288.92	18526.47	0.0504	7399.95	20862.03	0.0448
	Liaoning	18787.03	75742.00	0.0338	17738.54	50164.55	0.0504	18358.10	64025.77	0.0398
Average of northeast region		12738.05	48054.89	0.0316	12044.37	30617.91	0.0504	12403.05	38695.07	0.0405
North coastal region	Beijing	8755.56	13299.32	0.0690	9031.29	17988.44	0.0504	8698.65	12500.69	0.0736
	Hebei	18367.12	94587.92	0.0253	16702.99	47099.42	0.0504	17931.40	78833.94	0.0303
	Shandong	35554.82	122974.60	0.0479	35225.48	116272.50	0.0504	34648.14	105337.80	0.0553
	Tianjin	8837.86	20697.00	0.0452	8736.25	18568.91	0.0504	8309.77	11774.98	0.0794
Average of north coastal region		17878.84	62889.71	0.0469	17424.00	49982.32	0.0504	17396.99	52111.85	0.0597
Eastern coastal region	Jiangsu	36337.10	80714.90	0.0755	39025.31	124591.20	0.0504	35313.99	68170.36	0.0883
	Shanghai	15809.97	27764.93	0.0795	16827.84	43975.83	0.0504	15736.44	26854.50	0.0821
	Zhejiang	22978.83	45073.34	0.0737	24276.45	66478.16	0.0504	22766.06	42275.20	0.0785
Average of eastern coastal region		25041.97	51184.39	0.0762	26709.87	78348.40	0.0504	24605.50	45766.69	0.0830
Southern coastal region	Fujian	15915.61	26228.47	0.0807	16917.90	42070.63	0.0504	15286.98	19480.83	0.1082
	Guangdong	38565.52	62958.68	0.1040	43715.92	135743.10	0.0504	38137.81	58968.35	0.1105
	Hainan	1920.07	6740.99	0.0071	1827.11	1622.90	0.0504	1883.11	3487.61	0.0184
Average of southern coastal region		18800.40	31976.05	0.0639	20820.31	59812.21	0.0504	18435.97	27312.26	0.0790

		Original condition			Unconstrained condition (Scenario A)			Constrained condition (Scenario B)		
		GDP	Carbon dioxide	Shadow price	GDP	Carbon dioxide	Shadow price	GDP	Carbon dioxide	Shadow price
Middle reaches of the Yellow River	Henan	19911.22	64165.93	0.0469	19685.06	59517.39	0.0504	19441.02	54863.19	0.0545
	Inner Mongolia	8855.42	80532.10	0.0127	7433.94	19852.17	0.0504	8562.09	60410.90	0.0169
	Shanxi	6503.60	79082.14	0.0068	5416.13	12118.48	0.0504	6350.02	59642.02	0.0093
	Shaanxi	7473.56	44469.96	0.0150	6673.55	13834.00	0.0504	7149.19	27519.30	0.0248
Average of the middle reaches of the Yellow River		10685.95	67062.53	0.0204	9802.17	26330.51	0.0504	10375.58	50608.85	0.0264
Middle reaches of the Yangtze River	Anhui	11891.94	36043.87	0.0277	11318.30	20502.66	0.0504	11403.95	22277.06	0.0462
	Hubei	16883.29	42050.38	0.0438	16628.06	36618.72	0.0504	16306.86	30779.93	0.0601
	Hunan	14614.69	32937.97	0.0431	14399.33	28314.39	0.0504	14115.72	23232.74	0.0619
	Jiangxi	8050.76	19582.05	0.0325	7789.16	13085.54	0.0504	7796.91	13240.09	0.0498
Average of middle reaches of the Yangtze River		12860.17	32653.57	0.0368	12533.71	24630.33	0.0504	12405.86	22382.46	0.0545
Southwest region	Guangxi	8205.04	23680.11	0.0410	8007.22	19324.76	0.0504	7961.76	18444.56	0.0529
	Guizhou	3856.98	28857.79	0.0049	3510.32	4309.90	0.0504	3666.85	9269.75	0.0206
	Sichuan	23819.32	55061.86	0.0448	23528.31	48938.43	0.0504	22786.67	36237.77	0.0681
	Yunnan	6722.84	26226.34	0.0231	6268.32	12639.35	0.0504	6425.37	16198.71	0.0388
Average of northwest region		10651.05	33456.53	0.0285	10328.54	21303.11	0.0504	10210.16	20037.70	0.0451
Northwest region	Gansu	3526.99	20890.04	0.0060	3253.48	3886.30	0.0504	3382.90	7889.47	0.0214
	Ningxia	1016.72	19085.05	0.0010	905.32	1133.92	0.0504	984.80	6111.54	0.0059
	Qinghai	1099.02	5927.74	0.0038	1033.84	956.20	0.0504	1056.94	1599.53	0.0259
	Xinjiang	4566.29	38511.84	0.0086	3984.35	7816.63	0.0504	4403.21	23888.48	0.0148
Average of northwest region		2552.26	21103.67	0.0049	2294.25	3448.26	0.0504	2456.96	9872.26	0.0170
National average		13388.08	43527.93	0.0367	13388.08	34797.02	0.0504	13024.68	32943.95	0.0489

6. Conclusion and Discussion

Although the current effect of reducing China's carbon intensity is generally acceptable, two facts could not be avoided. First is the reduction of carbon intensity is partly benefited by the sustained slowdown in GDP growth. The real growth rate of GDP has continued to decline since 2011, and the growth rate dropped to 6.9% in 2014. Since the elasticity of GDP to carbon dioxide is less than 1, the decrease in GDP growth is objectively beneficial to reducing carbon intensity, which leaves the problem that how much GDP could be slowed down by China's national condition? If GDP growth recovered, reduction of carbon intensity would be a great challenge. Second is that the reduction of carbon intensity, to a certain extent, benefits from the "power rationing". During the period of 11th Five-Year, Jiangsu, Zhejiang, Shanxi and Hebei have sluiced the power limits in order to achieve the target of energy saving and emission reduction. During the whole period of 12th Five-Year, although most provinces in China claimed that the era of "power rationing" was ended, many of them still had the power rations plans at hand, and it was just because the economic slowdown did not pose pressure on the consumption of energy and electricity that power rationing was not enforced. This indicates that if a powerful and systematic energy saving and emission reduction scheme were not implemented, the provisional measures of "power rationing" could be re-staged with the future recovery of the economy. Therefore, in the context of the current national conditions, especially after the third Plenary Session of the 18th CPC Central Committee proposed the innovative exposition of "enabling the market to play a decisive role in resource allocation and the government to better play its role", the promotion of market-based energy saving and emission reduction measures represented by carbon trading is imperative.

This paper first uses the SFA method to estimate the shadow price of CO_2 in each province with the provincial panel data from 1995 to 2012. From the perspective of production function with the method of CFA-NLP, this paper simulates the potential effect of carbon trading in circumstance with constraints and without constraints respectively. The results indicate that: firstly the shadow price of carbon dioxide in each province shows a typical reduction trend from East to West. At the same time, it shows an overall upward trend in the sample years, and the growth also shows the typical downward trend from East to West. It is also found that the shadow price of carbon dioxide is asymmetric on the either side of carbon dioxide emission, and the shadow price on the right is lower than that on the left side. Secondly, in the unconstrained situation with maximizing the reduction of national carbon intensity as the goal, under the unconstrained national condition of the given GDP, carbon trading could reduce carbon intensity by 20.06%. If the hard constraints on the total amount of GDP in the country are relaxed, and economic growth and environmental protection are given the actual constraints, carbon trading could reduce the intensity by 22.20% with the GDP decreasing by 2.71%. Thirdly, arbon intensity in 2012 has successfully completed the phased targets of Copenhagen Conference. If the interprovincial transaction of carbon emission rights were introduced, the improvement process of carbon intensity could be effectively push forward, which could complete the overall requirements of the Copenhagen conference. The policy suggestions of this study can be reflected in the following.

Firstly, China should plan ahead to connect with other countries' carbon trading market and seize the main power of international carbon trading market. During the period of evolution, international carbon trading market formed two typical paths. First is the "top-down" model that is promoted by the international treaties. However, with the decline of the first model represented by Kyoto mode,[1] another path grows in importance. The second path is to develop their own carbon trading markets independently in each province, and forms the "bottom-up" model with mutual coordination and integration. Whether it is the "top-down" or "bottom-up" model of the international carbon trading market, a signal is undoubtedly released that the system connection has become an inevitable trend in the international carbon trading market (Pang *et al*., 2014). Therefore, China should actively seize the pricing power and discourse power of the international carbon trading market in advance before the international carbon trading market is completely construeted.

Secondly, carbon tax could be levied, which will play the transiting role in the short term, as well as the organic integrating role in long-term. Before the implementation of carbon trading, the collection of carbon tax is an important policy to reduce carbon emission across world. In international practice, the carbon trading mechanism and carbon tax mechanism have advantages and disadvantages, which forms the complementary relationship instead of replacing. More and more countries tend to implement both the two mechanisms. In the short term, if the construction of a national carbon trading market is difficult, the collection of carbon tax could play the transiting role. In the long run, the carbon trading is more suitable for large and medium-sized enterprises or large emission sources. Moreover, even if the carbon trading market is completed, the tax mechanism is still needed to make a constraint for small and micro business and residents. According to the preliminary plan of the Ministry of Finance, China's carbon tax policy may be introduced in the 13th Five-Year period. The tax rate drafted initially should have the effect on people's behavior, which indicates the additional social cost could motivate people to protect the environment. Only in this way could the institutional value of carbon tax or environmental tax be truly reflected (Chen, 2010). Actually, the estimation of carbon dioxide shadow price in the paper could provide the technical support for the rational formulation of differentiated carbon tax standards.

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