Valuation of Carbon Emission Rights Based on Shadow Price Approach - An Example of Pilot Provinces in China

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Abstract: The current volatile price of carbon trading in China requires a reasonable reference price, and research on the value of carbon emission rights is urgent. In this paper, the value of carbon emission rights in seven provinces and cities of Beijing, Tianjin, Shanghai, Fujian, Guangdong, Hubei and Chongqing from 2014 to 2021 is studied by constructing transcendental logarithmic production function and using shadow price method. It is found that the shadow prices of carbon emission rights in seven provinces and cities in China show a rising trend year by year, and all of them are significantly higher than the average transaction price. However, there are geographical differences, among which Beijing has the highest carbon emission rights value price with an average shadow price of 98,305.84 yuan per ton; Tianjin has the lowest carbon emission rights value with an average shadow price of 18,917.64 yuan per ton. It can be seen that the current carbon trading market is not well developed and the current trading price does not reflect the true value of carbon emission rights.

Keywords: Carbon trading; Value of carbon emission rights; Shadow price; Transcendental logarithmic production function

1 Introduction

The success of the industrial revolution and the intensification of global competition have enabled the country's economy to grow rapidly, but the resulting greenhouse effect has become a hot topic in the international community. After the United Nations Framework Convention on Climate Change proposed to control greenhouse gas emissions, the Kyoto Protocol for the first time proposed the use of market mechanisms to promote the solution of greenhouse gas emissions reduction, treating carbon dioxide emission rights as a kind of trading goods, since then the world region has gradually established a carbon emissions trading market. As a responsible power, China has taken the initiative to fulfill our emission reduction obligations. Since 2011, China has gradually launched carbon emissions trading pilot projects in nine provinces and cities: Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, Shenzhen, Fujian and Sichuan; In September 2020, China proposed the "carbon peak and carbon neutral" emission reduction target; In July 2021, the national carbon market was officially launched.

However, the current price of carbon trading in China is highly volatile and needs a reasonable reference price. Existing studies show that scholars prefer to adopt the shadow price method

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for research because shadow pricing is convenient and easy to accurately reflect the intrinsic value of emission rights[1]. For example, Chen and Xu (2021)[2] measured the average shadow price of CO_2 for 867 chemical companies from 2007-2012, which was 164 yuan per ton equivalent. The shadow price is an opportunity cost[3], which means the economic revenue that will be sacrificed by reducing one unit of CO_2 emissions[4], thus the shadow price can calculate the marginal abatement cost of carbon emission rights and become the guiding price for carbon emission rights[5]. Wang and Hu (2019) [6] then studied the regions where the seven carbon emission trading pilots in China are located, and compared the measured shadow prices with the average trading prices, and found a large deviation between the two.

Whether the pricing mechanism of China's carbon market is reasonable, whether the current price of carbon trading can effectively match the true value of carbon emission rights, and whether it can effectively contribute to the achievement of the national dual carbon goals, the answers to these questions require a reasonable assessment of the current value of carbon emission rights in an objective manner. Based on the policy background of "carbon neutrality and carbon peaking", this study investigates the value of carbon emission rights in pilot provinces through the shadow price method and proposes relevant policy recommendations, which provide reference values for the regulation and promotion of China's carbon trading market.

2 Model Introduction

Depending on the treatment of CO_2, the shadow price model for carbon emission rights can be divided into two types: The first one is based on the traditional production function, treating CO_2 emissions as an input variable[7] and constructing a transcendental logarithmic production function to calculate shadow prices[8]; the second one is based on the output function, treating CO_2 emissions as a non-desired output variable and GDP as a desired output variable, and constructing an SBM pairwise model[9][10] or using the directional distance function method[2][11] to measure the shadow price of carbon emission rights. Carbon emission reduction is both a social responsibility and a development opportunity. Carbon allowances can be circulated and traded in the market, and nowadays carbon emission rights have become an important asset for enterprises. Enterprises can use carbon emission rights assets to reasonably and legally emit carbon dioxide in their production and operation, and make efficient use of carbon emission credits to achieve emission reduction targets and gain revenue at the same time.

Therefore, in this study, it is argued that carbon emission rights should be treated as a factor of production for firms, and carbon dioxide emissions are treated as an input variable to construct a transcendental logarithmic production function to calculate the shadow price.

When there are only two factors of production, labor and capital, the traditional Cobb-Douglas production function can be constructed in the logarithmic form as in (1):

$$lnY = lnL + lnK + \varepsilon \tag{1}$$

Where L represents input labor, K represents input capital, Y represents GDP, and ε represents the stochastic disturbance term.

Adding the production factor of CO_2 emissions to the traditional production function to construct the transcendental logarithmic production function, which is more inclusive[12], and can reflect the interaction effects between various variables, with the equation as (2):

$$lnGDP = \alpha_1 lnL + \alpha_2 lnK + \alpha_3 lnCO_2 + \alpha_4 lnL \cdot lnK + \alpha_5 lnL \cdot lnCO_2 + \alpha_6 lnK \cdot lnCO_2 + \alpha_7 (lnL)^2 + \alpha_8 (lnK)^2 + \alpha_9 (lnCO_2)^2 + \varepsilon \quad (2)$$

According to the marginal production theory, the price of a factor of production is equal to its marginal productivity, and the partial derivative is applied to CO_2 emissions to obtain the shadow price of carbon emission rights P:

$$P = \frac{\partial GDP}{\partial CO_2} = \frac{GDP}{CO_2}(\alpha_3 + \alpha_5 lnL + \alpha_6 lnK + 2\alpha_9 lnCO_2) \quad (3)$$

3 Shadow price measurement of carbon emission rights

3.1. Data sources

The research subjects of this paper are the seven provinces and cities of Beijing, Tianjin, Shanghai, Fujian, Guangdong, Hubei and Chongqing, and the data are obtained from the statistical yearbooks of each province, China Statistical Yearbook and China Fixed Assets Statistical Yearbook from 2014-2021.

In this paper, we use the transcendental logarithmic production function method to estimate the shadow price of carbon emission rights in each province and city from 2014 to 2021, and the variables to be used are divided into input and output variables. In this paper, the number of employed people at the end of the year (L), the amount of investment in fixed assets (excluding farmers) (K), and carbon dioxide emissions (CO_2) are selected as input variables; The gross product (GDP) of each province and city was chosen as the output variable.

Among them, carbon dioxide emissions (CO_2) are measured using energy consumption data conversion, which is calculated using the IPCC method with the following formula:

$$CO_2 = \sum_{i=1}^{10} E_i \cdot CV_i \cdot CC_i \cdot COR_i \cdot (44/12) \quad (4)$$

In the above equation, E_i represents the total consumption of fuel type i; CV_i is the average low level heat content of fuel type i; CC_i is the carbon content per unit of energy; COR_i is the carbon to oxygen ratio, and 44/12 represents the carbon to carbon dioxide conversion ratio. Data of E_i are from the China Energy Statistical Yearbook, which mainly includes ten types of energy sources: raw coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas (LPG), refinery thousand gas and natural gas. Data of CC_i and COR_i are from "Guidelines for Provincial Greenhouse Gas Inventories (Trial)". The details are shown in Table 1:

Table 1 Conversion factors for each energy source in the calculation of CO_2 emissions

Fuel type	CV	CC	COR
Raw coal	20908 kJ/kg	26.37tC/TJ	0.94
Coke	28435 kJ/kg	29.5tC/TJ	0.93
Crude oil	41816 kJ/kg	20.1tC/TJ	0.98
Gasoline	43070 kJ/kg	18.9tC/TJ	0.98
Kerosene	43070 kJ/kg	19.6tC/TJ	0.98
Diesel	42652 kJ/kg	20.2tC/TJ	0.98
Fuel oil	41816 kJ/kg	21.1tC/TJ	0.98
LPG	50179 kJ/kg	17.2tC/TJ	0.98
Refinery thousand gas	45998 kJ/kg	18.2tC/TJ	0.98
Natural gas	38931kJ/m^3	15.3tC/TJ	0.99

3.2. The process of measuring the shadow price of carbon emission rights

3.2.1. Factor analysis

All data are first logarithmically processed, and then factor analysis is performed using SPSS software to determine the major components.

According to the results of the KMO test and Bartlett's test (Table 2), the KMO was 0.742, which is greater than 0.6, the sig value was 0.000, and the Bartlett sphericity test chi-square statistic was significant, indicating that there is a correlation between the variables and suitable for factor analysis.

Table 2 KMO and Bartlett's test

KMO sampling suitability number.		0.742
Bartlett's sphericity test	Approximate cardinality	3069.849
	DOF	36
	Sig.	0.000

Table 3 Explanation of total variance

Components	Initial eigenvalue			Extraction of the sum of squares of loads		
	Total	Percentage of variance	Cumulative Percentage	Total	Percentage of variance	Cumulative Percentage
1	7.972	88.583	88.583	7.972	88.583	88.583

Extraction method: principal component analysis.

From the total variance explanation table (Table 3), it is clear that only one component has an initial eigenvalue greater than 1, which is 7.972, with a variance percentage of 88.583%, indicating that component 1 explains most of the raw data information.

Table 4 Component score coefficient matrix

Variables	Score coefficient
lnL	0.119
lnK	0.113
$lnCO_2$	0.114
$lnL \cdot lnK$	0.122
$lnL \cdot lnCO_2$	0.123
$lnK \cdot lnCO_2$	0.122
$(lnL)^2$	0.120
$(lnK)^2$	0.113
$(lnCO_2)^2$	0.115

From Table 4, the following principal component expression y can be derived from the score coefficients of each variable:

$$y = 0.119lnL + 0.113lnK + 0.114lnCO_2 + 0.122lnL \cdot lnK + 0.123lnL \cdot lnCO_2 + 0.122lnK \cdot lnCO_2 + 0.120(lnL)^2 + 0.113(lnK)^2 + 0.115(lnCO_2)^2 \quad (5)$$

3.2.2. Regression analysis

A linear regression equation of log of GDP with component 1 is established, with lnGDP as the dependent variable and principal component y as the independent variable, with the following equation (6):

$$lnGDP = a * y + b \quad (6)$$

Regression analysis is also performed using SPSS software and the results are as follows:

Table 5 ANOVA

Models		Sum of Squares	Degrees of Freedom	Mean Square	F	Sig.
1	Regression	12.057	1	12.057	82.615	.000[b]
	Residual	7.881	54	0.146		
	Total	19.937	55			

As shown in Table 5 , the F-value is 82.615, the sig value is less than 0.05, and the model is significant overall.

Table 6 Regression coefficients and t-test

Models		Unstandardized coefficients		Standardized coefficients	t	Sig.	Covariance statistics	
		B	Standard errors	Beta			Tolerance	VIF
1	Constant	19.579	0.051		383.523	0.000		
	y	0.468	0.052	0.778	9.089	0.000	1.000	1.000

As can be seen from Table 6, the coefficient a is 0.468 and the constant b is 19.579, which are significant at 5% level and both pass the significance test. Bringing the coefficients into equation (6), combined with equation (5), we get:

$$lnGDP = 0.055692lnL + 0.052884lnK + 0.053352lnCO_2 + 0.057096lnL \cdot lnK + 0.057564lnL \cdot lnCO_2 + 0.057096lnK \cdot lnCO_2 + 0.05616(lnL)^2 + 0.052884(lnK)^2 + 0.05382(lnCO_2)^2 + 19.579 \quad (7)$$

Thus the shadow price of carbon emission rights is calculated as shown in (8):

$$P = \frac{\partial GDP}{\partial CO_2} = \frac{GDP}{CO_2}(0.053352 + 0.057564lnL + 0.057096lnK + 0.10764lnCO_2) \quad (8)$$

3.2.3. Results of carbon emission rights shadow price measurement

The regional GDP, CO_2 emissions, number of employed people at the end of the year and fixed asset investment (excluding farmers) of the pilot provinces are brought into the formula to find the shadow prices for each pilot province for each year, and the results are shown in Table 7 :

Table 7 Shadow prices in the corresponding provinces in the pilot areas (yuan/ton)

Regions	Beijing	Tianjin	Shanghai	Fujian	Hubei	Guangdong	Chongqing
2014	54499.05	14412.11	27170.31	23842.55	23854.40	32902.56	25923.71
2015	64745.39	15145.54	29120.53	26562.42	26015.65	35979.08	29015.71
2016	78444.72	17122.80	32441.46	24805.08	28155.33	38364.88	30372.72
2017	89225.62	18692.84	35300.01	33716.47	30759.00	41204.45	38450.20
2018	102244.79	19675.23	39665.09	35402.50	35488.47	43594.49	42475.41
2019	109583.43	20814.28	40538.19	36315.93	35933.88	47788.90	45715.69
2020	139679.21	21934.26	44057.85	37483.78	37807.85	48599.72	49120.15
2021	148024.55	23544.02	47359.48	38077.37	38719.22	48945.54	57322.51

Table 8 Descriptive statistics of the shadow price of carbon emission rights in each pilot province

Province	Minimum	Maximum	Mean	Standard deviation	Growth rate	Sort
Beijing	54499.05	148024.55	98305.84	33484.88	171.61%	1
Tianjin	14412.11	23544.02	18917.64	3217.70	63.36%	7
Shanghai	27170.31	47359.48	36956.61	7162.58	74.31%	4
Fujian	23842.55	38077.37	32025.76	5952.55	59.70%	6
Hubei	23854.40	38719.22	32091.72	5668.73	62.31%	5
Guangdong	32902.56	48945.54	42172.45	6100.05	48.76%	2
Chongqing	25923.71	57322.51	39799.51	10925.75	121.12%	3

4 Conclusions and Recommendations

4.1. Research conclusions

(1) The shadow price of carbon emission rights is increasing year by year

By comparing the measured shadow prices of carbon emission rights in each pilot province from 2014 to 2021, it is found that the shadow prices in all pilot provinces are increasing year by year, which may be due to the fact that with the establishment of the carbon emission trading market in each pilot province and the implementation of strict environmental protection policies, the importance of carbon allowances gradually emerges and the market value of carbon emission rights is increasingly valued by enterprises. As can be seen from Table 8, in order of the average value of shadow prices, from high to low are Beijing, Guangdong, Chongqing, Shanghai, Hubei, Fujian and Tianjin; in order of the growth of shadow prices, from high to low are Beijing, Chongqing, Shanghai, Tianjin, Hubei, Fujian and Guangdong.

(2) There are geographical differences in the shadow price of carbon emission rights

Except for Fujian and Hubei, where the shadow prices are close, the other regions have huge differences in shadow prices, especially in Beijing, where the shadow price of carbon emission rights is significantly higher than other pilot provinces every year, and its average shadow price is as high as 98,305.84 yuan per ton, which is more than 5 times the average shadow price of Tianjin, and 2 to 3 times the average shadow price of the corresponding other pilot provinces, indicating that Beijing is under the greatest pressure to reduce carbon emissions. However, the high shadow price in Beijing is partly due to the composition of the industrial structure. Compared to other provinces and cities, Beijing has fewer primary and secondary industries and more tertiary industries, so even though CO_2 emissions will be relatively low, the regional economic development remains high, which leads to a significantly higher shadow price than other provinces and cities.

The existence of geographical differences in shadow prices also indicates that China's carbon emission trading market has great potential for development. In the future, consideration can be given to transferring the emission reduction targets from regions with high shadow prices to regions with low shadow prices, so as to reasonably distribute the emission reduction pressure in different regions and thus achieve the national carbon emission reduction targets.

(3) The shadow price of carbon emission rights is significantly higher than the average trading price

The shadow price is a theoretical price that takes full account of the scarcity of resources and is very demanding on market conditions and resource allocation. The shadow price will only be equal to the market price if the market in which the resource is located is optimally efficient, supply and demand are in equilibrium, and the scarce resource is utilized to optimal use, so the shadow price can be used as a guiding price for carbon emission right trading. According to the existing trading data of each pilot market, the average annual transaction price of all pilot markets in China does not exceed 100 yuan per ton, while the shadow price of carbon emission rights in the corresponding provinces of the eight pilot markets is significantly higher than the average transaction price. This indicates that the current carbon emission trading price does not reflect the actual cost benefits of local carbon emissions and the real value of carbon emission rights, the carbon trading market is inefficient and imperfectly developed, and the "invisible hand" of the market plays a very limited regulatory role.

4.2. Policy Recommendations

The development plan of China's carbon emission trading market should be based on the national reality, promote benign exchanges between China and other countries, and actively study and learn from the advanced experience of mature carbon emission markets abroad. Actively improve relevant supporting normative policies, appropriately introduce competitive mechanisms and regulatory mechanisms, establish a sustainable carbon emission trading system, promote open and transparent market transactions, and stimulate market vitality. Coordinate the relationship between the government and the market, the government should gradually reduce its intervention and let the market become the main driving force. Strengthen the awareness of energy conservation and emission reduction of enterprises, and enhance the main responsibility of energy conservation and emission reduction of enterprises.

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