

# Evaluation of Carbon Emission Performance and Estimation of CO<sub>2</sub> Abatement Costs for Provinces of China: A Non-Parametric Distance Function Approach

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## Abstract

In this research, 30 provinces (municipalities and autonomous regions) in mainland China were selected as research subjects. Inputs elements such as coal, oil, natural gas, capital, and labor were selected, while GDP and carbon dioxide emissions in each province were taken as outputs elements, and distance function of carbon dioxide emissions was derived with the Malmquist index model. Shadow price and emission reduction cost of CO<sub>2</sub> emission in each province were analyzed in order to measure the environmental cost of economic growth and the economic cost of pollution reduction.

## Keywords

Carbon Emission, Pollution Reduction, Shadow Price, Distance Function

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## 1. Introduction

More and more public concerns go to the many global environmental issues arising from climate changes and other related problems. A forced consensus has been made under such context, which includes reduction of carbon dioxide, methane, and other greenhouse gases emissions, and move on to a new path of low-carbon and high economic grow. For reduction of carbon dioxide, the key is to decrease consumption demand for fossil energy, and improved energy utilization efficiency [1].

## 2. Data Source and Models Setting

### 2.1. Data Source and Selected Indicators

Let  $i = 1, 2, \dots, 30$  representing the 30 provinces (municipalities, autonomous

regions) in Chinese mainland (excluding Tibet for lack of data),  $t = 1, 2, \dots, 15$  for to the 10 years from 2003 to 2012, and the vector  $x_j$  ( $j = 1, 2, 3$ , respectively) for the three input factors of energy, labor, and capital; the fossil energy consumption of coal, oil, and natural gas represent the resource endowment and energy consumption structure of each province; and the main output consists of regional GDP and carbon dioxide emission, where GDP is symbolized  $y$  as the desirable output and carbon dioxide emission is symbolized  $b$  as the undesired output.

The energy consumption data is taken from CHINA ENERGY STATISTICAL YEARBOOK (2003-2012), and the consumption of fossil energy in each province is derived from the total coal from the corresponding energy balance sheets (2003-2012). Total oil and natural gas consumption; labor compensation is expressed by average staff salary, capital investment is replaced by fixed asset investment, labor, capital and provincial GDP data are from the "China Statistics Yearbook China Statistical Yearbook" (2003-2012), and base year is 2002 [2] [3] [4].

## 2.2. Non-Parametric Directional Distance Function (DDF)

Assume that the inputs and outputs satisfy: 1) strong disposability of inputs and desirable outputs; 2) weak disposability of undesired output; 3) simultaneous presence of desirable outputs and bad outputs. The objective programming of DEF can be expressed as follows:

$$\begin{aligned} D^i(x_j^i, y^i, b^i; g_y, g_b) &= \text{Max} \beta^i & (1) \\ \text{St. } X\lambda &\leq x^i, \\ Y\lambda &\geq y^i + \beta^i g_y, \\ B\lambda &\leq b^i - \beta^i g_b \\ \beta^i, \lambda &\geq 0, i = 1, 2, \dots, 30 \end{aligned}$$

In order to compare differentiation of carbon emission efficiency between provinces, the direction vector in the formula is defined as  $g = (g_y, g_b) = (0, b)$ , which means that the validity of the targeted province was evaluated by lowering emission on the condition of not reducing the economic output.

## 2.3. Shadow Price

Along the efficient path  $(y^*, b^*)$  of the observation value  $(y, b)$ , the formula for shadow price on technological frontiers can be derived with the results of function  $D(\cdot)$ . Let  $p_y^i$  be the price of desirable outputs (GDP) in  $i$ th Province, which, for convenience's sake, is expressed as  $p_y^i$  with value of 1, and thus, the shadow price of undesirable outputs (carbon dioxide, namely) in  $i$ th Province, which is  $p_b^i$ , can be expressed as follows:

$$p_b^i = p_y^i \times \frac{\partial D(x^i, y^{i*}, b^{i*}) / \partial y^{i*}}{\partial D(x^i, y^{i*}, b^{i*}) / \partial b^{i*}} \times \frac{\delta_1^b}{\delta_1^y} \quad (2)$$

where,  $\frac{\delta_i^b}{\delta_i^y}$  represents inefficiency factors, with definition expressed as below:

$$\delta_i^b = \frac{1}{1 - D(x^i, y^i, b^i) / (g_b / b^*)} \quad (3)$$

$$\delta_i^{by} = \frac{1}{1 - D(x^i, y^i, b^i) / (g_y / y^*)} \quad (4)$$

### 3. Empirical Analysis Based Study of Carbon Emissions Performance and Marginal Cost

#### 3.1. Carbon Emission and Emission Intensity

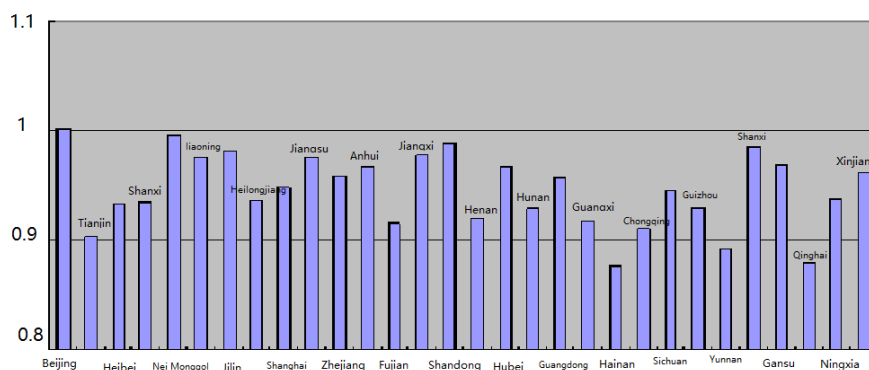
According to the data on energy consumption in all recorded industries released by “China Statistical Yearbook”, the energy consumption of various industries is divided into 9 categories. And in the paper, 8 categories, because of generation of electricity powers ultimately originating from coal, oil, natural gas, etc., have been considered as carbon dioxide emission source: coal; coke; crude oil; gasoline; kerosene; diesel oil; fuel oil; and natural gas. The calculation of carbon dioxide of the above 8 categories was performed by using GHG Protocol of IPCC [5] [6] [7].

#### 3.2. Empirical Analyses Based on Emission Performance and Marginal Cost of Emission Reduction

The above data and DEA (data envelopment analysis) were both applied for constructing a Malmquist model and an two-stage BCC output-oriented (variable returns to scale) model, and calculation was also performed on the value of the distance function and shadow price of carbon dioxide emission in each province of China.

##### 3.2.1. DDF and Carbon Emission Efficiency

It is seen in **Figure 1** that in each province, the carbon emission efficiency is closely associated with the level of economic development, resource endowment and structure of energy consumption. During the decade from 2003 to 2012, China’s east coast provinces like Guangdong, Shanghai, Tianjin and its central



**Figure 1.** Carbon Emissions Performance in all provinces (2003-2012).

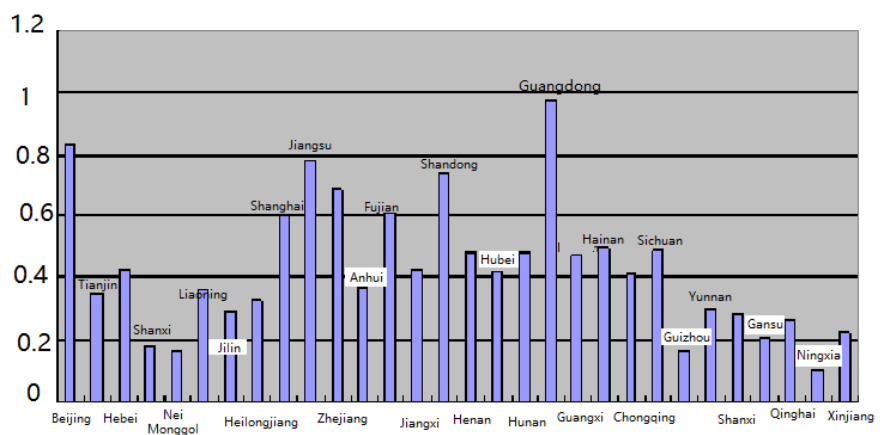
developed provinces had smaller distance function values and higher relative carbon emission performance. Hainan, due to its low energy input also has high carbon emission performance and low carbon emissions. As for Inner Mongolia, Shaanxi, Guangxi, and less-developed central provinces in the Western China, such as Anhui and Hubei, showed large distance function values, more than half of which have exceeded 0.9, indicating that low carbon emission efficiency will bring great room for emission reduction.

### 3.2.2. Shadow Price and Marginal Cost of Emission Reduction

In **Figure 2**, it is understood that carbon emission costs of each province are also strongly correlated with the level of economic development, resource endowment, and structure of energy consumption. During the period between 2003 and 2012, China's east coast provinces Beijing, Guangdong, Shanghai, Tianjin, Jiangsu and the central developed provinces had high shadow prices and relatively high emission reduction costs. It is possibly high efficient carbon emissions that leaves less and less room for resetting emission reduction target for a given resource, leading to more and more elevation of shadow price for pollution emissions. So, with limited economic growth boosted by emission market, these provinces take measure to carry out industrial structure upgrade and technology innovation so that they can expand production outputs and develop stably in the future.

For central provinces such as Jiangxi, Anhui, Hubei and Hunan, although with relatively high emissions performance, their shadow prices, by contrast, is undesirably low, and the increasing carbon emissions help not much to their economies. In effect, these areas are facing urgent air pollution problems to be solved immediately while they appealingly have developed economically but at the cost of environment. Therefore, these provinces start more intensive input in emission problems until it reduces to a reasonably low growing pace, and promote a development mode featuring low energy consumption and high economy growth.

For the northern and western regions of Inner Mongolia, Liaoning, Shaanxi,



**Figure 2.** Marginal cost of carbon emission in each province (2003-2012).

and Gansu, the shadow prices are small, indicating that the marginal cost of carbon emissions in these provinces is relatively small. Southwestern Yunnan and Guizhou also have lower shadow prices, indicating lower cost for carbon emissions. Because these provinces have slow economy lagging behind other counterparts in China, but with abundant natural resources, these areas are allowed a looser control over carbon emissions so that they can make economic effort to catch up.

#### 4. Conclusions and Policy Proposal

At present, China's economic development has been facing two major problems: first, the resources reserve rate per capita are low and employment pressure looms large; second, the resource element reserve rate per capita is low and economic production is extensive. Under such circumstances, it is urgent to explore a way that suits China's national conditions to make progress in environment, politics and society.

In this research, 30 provinces (municipalities and autonomous regions) in mainland China were selected as the research subjects, inputs elements such as coal, oil, natural gas, capital, and labor were selected, GDP and carbon dioxide emissions in each province were taken as outputs elements, and all taken together, distance function of carbon dioxide emissions was derived with the Malmquist index model. Taking consideration of effect of structure of energy consumption, capital, labor on desirable outputs (here the GDP) and undesired outputs (carbon dioxide emissions), estimation was made on environment costs resulting from uncontrolled pursuit of economic growth and economic costs to reduce emission during economic production by referring to two-stage BCC model that was used to analyze the shadow price and reduction costs of CO<sub>2</sub> emissions in each province [8] [9]. Main results obtained from the analysis are as follows:

- There are obvious differences in carbon emissions efficiency between provinces. The eastern coast and the more developed provinces in the central region have higher carbon emission performance, and there is less room for further reductions, which signaling optimization of energy structure and industrial upgrading; while the central and less developed provinces in the central and west China have relatively low carbon emissions, and introduction of new technology and improved energy efficiency will promote economic development and decrease emissions reduction burdens.
- The shadow price of carbon emissions works in a strong pattern: a clear correlation forms between shadow prices and carbon emissions and the level of economic growth; and normally, the provinces where witness rapid increase in carbon emission but lower economic growth rate, are subject to relatively higher shadow price and emission reduction costs, and vice versa.
- Effect of carbon emission reduction policy is attributed with regional interaction. This study shows that marked differentiation of conditions and poten-

tial for carbon dioxide emission reductions in targeted provinces in China, and accordingly set distinguished emission goals and policy and system, are beneficial to optimizing regional source distribution, plausibly exploiting differentiation effect of emission reduction, and facilitating sound development of emission market as well. Interestingly enough, the emission reduction of carbon dioxide in a country is connected and disconnected with the international carbon emission reduction. In other words, the two both are involved in effect of price for China's emission reduction and supply-and-demand dynamics present in global emission market; and on the other hand, working independently, the China's emission market is relatively more micro-manageable than global market, resulting in integrated effect of emission policy.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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