Shadow Prices of SO_2 Abatements for Regions in China

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Abstract.

We use the linear programming approach to examine the overall macroeconomic performance and compute shadow prices of SO_2 emission abatements for thirty regions in China during the 1996-2002 period. Our major findings are as follows: On average, the east is the most efficient and the west is the most inefficient during these seven years. The average efficiency of those regions with serious acid rain is higher than the national average. Shadow prices in the west area are the highest, while shadow prices in the central area are the lowest. Shadow prices of the regions with serious acid rain are lower than the national average shadow price, implying that China should start with SO_2 abatements from these regions.

Key words: *Shadow price, SO_2 abatements, output distance function, China*

I. Introduction

Air pollution alone contributes to the premature death of more than a quarter of a million people each year (World Bank, 1998). One of the main sources of air pollution is acid rain, and the main reason of acid rain forms is that there is too much sulfur dioxide (SO_2) in the air.

China is the third largest acid rain belt in the world. During the last ten years, because SO_2 emissions have increased day by day, China is now only behind Europe and North America. The provinces with the most serious acid rain problem include: Sichuan, Guizhou, Guangdong, Guangxi, Hubei, Hunan, Jiangxi, Zhejiang, and Jiangsu (Science Museums of China, 2006).

The dangers of acid rain to the environment include: degradation of forests, lakes become acidic, fish die, farmland and soil become acidic, poisonous heavy metal pollution increases, and vegetables and fruits drop in production on a large scale. Dangers from SO_2 emissions to the mankind are: asthma, coughing, headaches, and allergies of the eyes, nose, and throat. Therefore, the Chinese government should face up to the problem of SO_2 emission.

Although air pollution abatement is mutually beneficial to China and the rest of the world, people may worry that a drastic reduction in air pollution will hamper economic growth. An economy's macroeconomic policies generally have two objectives: creation of wealth and good living conditions for citizens. Gross domestic product (GDP) is commonly used in assessing an economy's wealth, but it does not constitute a measure of wealth without dealing with environmental issues adequately. We thus calculate environmental degradation as a correction factor into our regular definition of economic growth (van Dieren, 1995).

We do know that an economic growth depends on industry, especially in a developing country, but growth in industry will cause pollution. Thus, we should calculate how much will industries pay for pollution abatement in a developing country.

Using the output distance function is a popular way to estimate the shadow price of pollution abatement. Swinton (1998) provides estimates of the shadow price of SO_2 abatement using the output distance function approach for Illinois, Minnesota, and Wisconsin coal-burning electric plants.

Kumar and Rao (2002) provide estimates of firm specific marginal abatement costs of suspended participate matters (SPM) for the thermal power sector in India. They use the output distance function framework to estimate marginal abatement costs or shadow prices of the pollutant for individual plants.

Coggins and Swinton (1996) take an output distance function approach to estimate the shadow price of SO_2 abatement. Färe and Zieschang (1991) develop a method for computing output shadow prices when total cost and input prices are exogenous, using the indirect output distance function.

Hu (forthcoming) uses the input distance function to estimate the efficient pollution abatements of regions in China, but does not compute the shadow prices of pollution. In this paper we take the output distance function approach to estimate the efficiency and the shadow prices of SO_2 abatements for regions of China.

The aim of this paper is to measure China's macroeconomic performance by taking into account undesirable externalities of economic growth using data over the period 1996-2002. In this study, performance is defined in light of an economy's ability to provide its citizens with both more wealth and a less polluted environment. We use the output distance function to examine the macroeconomic performance and compute shadow prices of SO_2 emission in China.

Based on the economic theory of production, inputs (such as capital and labor) are transformed into output (such as gross domestic product, GDP) in the production process. Environmental disamenities are then added and the analysis show an undesirable output. The SO_2 emissions are regarded as undesirable output.

There are four sections in this paper. After this introductory section, the next section provides an introduction to the output distance function and describes the data sources. Section 3 presents the empirical results. Section 4 concludes this paper.

II. Method and Data Sources

Output Distance Function

A producer employs input vector $\boldsymbol{x} = (x_1, ..., x_N) \in R_+^N$ to produce output vector $\boldsymbol{y} = (y_1, ..., y_M) \in R_+^M$. According to Shephard (1970), the output distance function can be defined as follows:

$$D_o(\boldsymbol{x}, \boldsymbol{y}) = \inf\left\{ \theta : \boldsymbol{y}/\theta \in P(\boldsymbol{x}) \right\}, \tag{1}$$

where $P(\boldsymbol{x})$ is the output sets of production technology, describing the sets of input vectors , ***x*,** that can produce the output vector, ***y*.** That is,

$$\mathrm{P}(\boldsymbol{x}) = \{\ \boldsymbol{y}:\ \boldsymbol{x} \text{ can produce } \boldsymbol{y}\}. \tag{2}$$

We note that $\boldsymbol{y} \in P(\boldsymbol{x})$ if and only if $D_o(\boldsymbol{x},\boldsymbol{y}) \le 1$, and that the distance function is homogeneous of degree +1 in the outputs.

Of particular interest for our purposes are the disposability properties of technology with respect to outputs, especially undesirable output. Specifically, we wish to allow for regulation which restricts the ability of producers to costlessly dispose of undesirable byproducts of the production process. To that end we allow for what we call weak disposability of outputs, i.e., if $\boldsymbol{y} \in P(\boldsymbol{x})$ and $\theta \in [0,1]$, then $\theta \boldsymbol{y} \in P(\boldsymbol{x})$, but we do not necessarily allow for strong (free) disposability, which requires that if $\boldsymbol{y}' \le \boldsymbol{y} \in P(\boldsymbol{x})$, then $\boldsymbol{y}' \in P(\boldsymbol{x})$. Under weak disposability, in contrast to strong disposability, reduction of a byproduct can only be achieved by simultaneously reducing some desirable output(s). This is consistent with regulations which require abatement or cleanup of pollutants. Since that abatement is also resource-consuming, there is an associated opportunity cost of foregone marketable output.

Suppose that $P(\boldsymbol{x})$ is convex. Then the output distance function $D_o(\boldsymbol{x},\boldsymbol{y})$ and revenue function $\mathrm{R}(\boldsymbol{x},\boldsymbol{r})$ are dual (Färe and Primont, 1995):

$$\mathrm{R}(\boldsymbol{x},\boldsymbol{r}) = \max_{\boldsymbol{y}}\{\ \boldsymbol{r}\boldsymbol{y}\ :\ D_o(\boldsymbol{x},\boldsymbol{y}) \le 1\}, \tag{3}$$

$$\mathrm{D_o}(\boldsymbol{x},\boldsymbol{y}) = \sup_{\boldsymbol{r}}\{\ \boldsymbol{r}\boldsymbol{y}\ :\ R(\boldsymbol{x},\boldsymbol{r}) \le 1\}, \tag{4}$$

where $\boldsymbol{r} = (r_1,...,r_M)$ denotes the output price vector and $\boldsymbol{r}\ \boldsymbol{y}$ is the inner product of the output prices and quantity vectors. Equation (3) states that the revenue function can be derived from the output distance function by minimization over outputs ***y*,** while equation (4) represents that the output distance is obtained from minimization with respect to output prices ***r***.

Suppose that both $D_o(\boldsymbol{x},\boldsymbol{y})$ and $\mathrm{R}(\boldsymbol{x},\boldsymbol{r})$ are differentiable. The revenue function can be represented by the following Lagrange problem:

$$\max_{y} \; R(\boldsymbol{x},\boldsymbol{r}) = \; \boldsymbol{r}\,\boldsymbol{y} + \lambda(D_o(\boldsymbol{x},\boldsymbol{y}) - 1), \tag{5}$$

where λ is the Lagrangian multiplier. Applying the envelope theorem, we have the output shadow prices vector $\boldsymbol{r}^* = \left(r_1^*,\ldots,r_M^*\right)$ by differentiating the revenue function with respect to outputs,

$$\boldsymbol{r}^* = \nabla_y R(\boldsymbol{x},\boldsymbol{r}) = \lambda \cdot \nabla_y D_o(\boldsymbol{x},\boldsymbol{y}). \tag{6}$$

The shadow prices for the undesirable output can be interpreted as the measure of the marginal cost of reducing it to the economy. Equation (6) indicates that the ratio of the shadow prices of output *j* and output *k* is

$$\frac{r_j^*}{r_k^*} = \frac{\partial D_o(\boldsymbol{x},\boldsymbol{y})/\partial y_j}{\partial D_o(\boldsymbol{x},\boldsymbol{y})/\partial y_k}. \tag{7}$$

Equation (7) indicates the relative shadow prices of desirable output and undesirable output. Suppose that, the market price of desirable output is observable and equals its shadow prices. We then could calculate the shadow prices of undesirable output by the following formula (Färe et al., 1993).

$$r_j^* = r_k^* \cdot \frac{\partial D_o(\boldsymbol{x},\boldsymbol{y})/\partial y_j}{\partial D_o(\boldsymbol{x},\boldsymbol{y})/\partial y_k}. \tag{8}$$

This study will employ equation (8) to calculate the shadow prices of SO_2.

Parametric Linear Programming

In order to apply the shadow prices formula, we have to parameterize and calculate the parameters of the output distance function. An appropriate functional form to the output distance function would ideally be flexible, easy to calculate, and permit the imposition of homogeneity. The flexible translog functional form provides a second-order Taylor approximation to the unknown technology. It satisfies all the above criteria and has been used by many researchers (Färe et al., 1993; Lovell et al., 1995; Hailu and Veeman, 2000).

More important for our purposes, it does not impose strong disposability of outputs. The translog distance function with M outputs and N inputs is specified as:

$$\ln\ D_o(x,y) = \alpha_0 + \sum_{n=1}^{N}\beta_n \ln x_n\ + \sum_{m=1}^{M}\alpha_m \ln y_m\ + \frac{1}{2}\sum_{n=1}^{N}\sum_{n'=1}^{N}\beta_{nn'}(\ln x_n)(\ln x_{n'})$$

$$+\frac{1}{2}\sum_{m=1}^{M}\sum_{m'=1}^{M}\alpha_{mm'}(\ln y_m)(\ln y_{m'}) + \sum_{n=1}^{N}\sum_{m=1}^{M}\gamma_{nm}(\ln x_n)(\ln y_m). \quad (9)$$

This research employs the linear programming suggested by Aigner and Chu (1968) to estimate unknown parameters. This method relies on the minimization of the sum of deviations of the values of the logarithmic values of the output distance from the frontier. In other words, we try to estimate the parameters of a deterministic translog output distance function by solving the following problem:

$$\max\ \sum_{k=1}^{K}\left[\ln D_{\text{o}}\left(\boldsymbol{x}^k,\boldsymbol{y}^k\right) - \ln 1\right], \quad (10)$$

subject to

$$\text{(i)}\ \ln D_o\left(\boldsymbol{x}^k,\boldsymbol{y}^k\right) \le 0, \qquad k = 1,\dots,K$$

$$\text{(ii)}\ \frac{\partial \ln D_o\left(\boldsymbol{x}^k,\boldsymbol{y}^k\right)}{\partial \ln y_m^k} \ge 0, \qquad m = 1,\dots,i,\ k = 1,\dots,K$$

$$\text{(iii)}\ \frac{\partial \ln D_o\left(\boldsymbol{x}^k,\boldsymbol{y}^k\right)}{\partial \ln y_m^k} \le 0, \qquad m = i+1,\dots,M,\ k = 1,\dots,K$$

$$\text{(iv)}\ \frac{\partial \ln D_o\left(\boldsymbol{x}^k,\boldsymbol{y}^k\right)}{\partial \ln x_n^k} \le 0, \qquad n = 1,\dots,N,\ k = 1,\dots,K$$

$$\text{(v)}\ \sum_{m-1}^{M}\alpha_m = 1,\ \sum_{m'=1}^{M}\alpha_{m'm} = \sum_{m=1}^{M}\gamma_{nm} = 0, \qquad m = 1,\dots,M,\ n = 1,\dots,N$$

$$\text{(vi)}\ \alpha_{mm'} = \alpha_{m'm}, \qquad m = 1,\dots,M,\ \ m' = 1,\dots,M$$

$$\beta_{nn'} = \beta_{n'n}, \qquad n = 1,\dots,N,\ \ n' = 1,\dots,N$$

where k = 1,…, K indexes individual observations; m = 1,…, M indexes the mth output; n =

1,…, N indexes the nth kind of input; $\ln D_o(\boldsymbol{x}, \boldsymbol{y})$ has an explicit functional form as in equation (9); and the first i outputs are desirable and the next ($M - i$) outputs are undesirable.

The objective function ‘minimizes’ the sum of the deviations of individual observations from the frontier of technology. Since the distance function takes a value of less than or equal to one, the natural logarithm of $D_o(\boldsymbol{x}^k, \boldsymbol{y}^k)$ is less than or equal to zero, and the deviation from the frontier for observation k, $\ln D_o(\boldsymbol{x}^k, \boldsymbol{y}^k) - \ln 1$, is less than or equal to zero, hence making the ‘max’.

The first set of constraints labeled (i) restricts individual observations to be on or below the frontier of the technology. The constraints in (ii) ensure that the desirable outputs have nonnegative shadow prices and those in (iii) ensure that the undesirable outputs have non-positive shadow prices. The constraints in (iv) say that the output distance will not increase with an increase with any input. The constraints in (v) impose homogeneity of degree +1 in outputs, which also ensures that technology satisfies weak disposability of outputs. The final set of constraints in (vi) imposes symmetry.

Data Sources

Capital and labor are two major inputs in production, and when measuring a nation’s overall output, gross domestic product (GDP) is commonly used. For example, Färe et al. (1994) analyze the productivity growth of OECD countries, by considering capital and labor as inputs and GDP as an output. Chang and Luh (2000) adopt similar inputs and outputs to analyze the productivity growth of ten Asian economies.

There are two inputs and two outputs. We take capital formation and labor force as two inputs, GDP as a desirable output, and SO_2 as an undesirable output. The data of regional labor employment are established from the China Statistical Yearbook, and data of GDP output in each region are collected as stated previously. Real capital stocks in 1996 prices are constructed based on Li’s method (Li, 2003; Hu et al., 2005; Hu, forthcoming). Monetary inputs and outputs such as GDP and capital stock are deflated to 1996 values.

[Insert Table 1 about here]

The thirty regions are categorized into three areas. The three areas are the east area (abbreviated as ‘E’), the central area (abbreviated as ‘C’), and the west area (abbreviated as ‘W’).

III. Empirical Results

This study employs the mathematical programming software LINGO 6.0 to compute the parameters of the translog output distance function. Table 2 shows the values of estimated parameters. These parameter estimates are used to calculate the technical efficiencies and the shadow prices of SO_2 reduction for each region in each year. Note that the price of the desirable output (real GDP) is exactly one.

[Insert Table 2 about here]

Table 3 lists the macroeconomic efficiency scores with SO_2 emissions considered and the shadow prices of SO_2.

[Insert Table 3 about here]

The most efficient regions during the 1996-2002 period are respectively: Ningxia (W) in 1996, Hebei (E) and Fujian (E) in 1997, Hebei (E), Shanghai (E), and Shanxi (C) in 1998, Shanghai (E) in 1999, Guangdong (E) in 2000, Guangdong (E) in 2001, and Guangdong (E) and Tibet (W) in 2002. On average, the east is the most efficient and the west is the most inefficient during these seven years.

Tibet (W) has the highest shadow price of SO_2 emission abatement during the seven years: 60.4, 72.7, 65.4, 70.3, 72.7, 74.4, and 75.4 million RMB in 1996 prices per ton, respectively. On average, the shadow prices in the west area are the highest - that is, the opportunity cost of SO_2 emission is the heaviest in the west area, while the shadow prices in the central area are the lowest.

Table 4 shows the mean difference between the major acid rain regions (including Sichuan, Guizhou, Guangdong, Guangxi, Hubei, Hunan, Jiangxi, Zhejiang, and Jiangsu) and other areas. The average efficiency of regions with serious acid rain is higher than the national average efficiency. The shadow prices of these regions are lower than the national average shadow price. Therefore, China should carry on the work of SO_2 emission abatement from regions with serious acid rain.

[Insert Table 4 about here]

We now use the non-parametric test to check the correlation between the periods and regions. Because the numbers of periods and regions are both strictly greater than two, we use the Kruskal-Wallis test. Tables 5 and 6 show the results.

[Insert Table 5 about here]
[Insert Table 6 about here]

Tables 5 and 6 present that the shadow prices of SO_2 in those seven years do not have a significant change. However, the shadow prices of SO_2 in the three regions do have significance difference.

We next want to know which two areas have differences. Therefore, we use the Kruskal-Wallis multiple comparison approach to check which two areas show a significance difference. Table 7 provides that shadow prices of SO_2 between the east and central areas, and between the east and west areas have significant differences.

[Insert Table 7 about here]

SO_2 emission abatement is very urgent for China. The opportunity cost of SO_2 emission abatement looks quite low relatively, especially in regions with serious acid rain, and there is hope for improvement in air pollution. There is no reason to refuse SO_2 emission abatement.

IV. Concluding Remarks

This paper measures China's macroeconomic performance by incorporating undesirable externalities of economic growth using the data over the period 1996-2002. We take capital formation and labor force as two inputs, GDP as a desirable output, and SO_2 as an undesirable output. The output distance function is used to examine the macroeconomic performance and compute shadow prices of SO_2 emission in China.

Our major findings are as follows: On average, the east area is the most efficient and the west area is the most inefficient during these seven years. Shadow prices in the west area are the highest, while shadow prices in the central area are the lowest. The average efficiency of regions with serious acid rain is higher than the national average. The shadow prices of these regions are lower than national average shadow price. Shadow prices of SO_2 abatement are lower in serious acid rain regions than that in other regions.

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Table 1. Summary Statistics of Inputs and Outputs by Year

		1996	1997	1998	1999	2000	2001	2001
Inputs								
Capital Stock (100 million RMB)	Mean	12284.76	13700.43	15323.95	16683.52	16683.52	19481.79	20938.28
	Std. Deviation	11357.83	12658.12	14131.38	14900.03	14900.03	16617.02	17539.96
Number of Employed Labor (10,000 persons)	Mean	2094.59	2122.22	2114.21	2083.13	2199.30	2087.02	2125.99
	Std. Deviation	1541.44	1562.38	151.96	1557.86	1562.84	1582.87	1574.98
Outputs								
Gross Domestic Product (100 million RMB)	Mean	2266.30	2510.15	2525.91	2506.04	2562.14	2630.90	2767.73
	Std. Deviation	1747.58	1948.48	1954.61	1950.36	2027.10	2092.10	2231.96
Volume of Sulfur Dioxide Emissions (tons)	Mean	454451.43	454209.77	531007.07	486698.33	528694.57	501145.33	503993.53
	Std. Deviation	348019.43	348926.06	420839.03	375724.06	419936.12	399799.52	393258.32

Note:

(1) The monetary values are in 1996 prices.

(2) Data source: China Statistical Yearbook, 1997-2003.

Table 2. Parameter Estimates

$\boldsymbol{\alpha}_{\mathbf{output}}$		$\boldsymbol{\alpha}_{\mathbf{output,\ output}}$		$\boldsymbol{\beta}_{\mathbf{intput}}$		$\boldsymbol{\beta}_{\mathbf{intput,\ input}}$		$\boldsymbol{\gamma}_{\mathbf{intput,\ output}}$	
α_1	2.10353	α_{11}	0.14217	β_1	-3.55517	β_{11}	0.25887	γ_{11}	-0.05726
α_2	-1.10353	α_{12}	-0.14217	β_2	0.35093	β_{12}	0.04077	γ_{12}	0.05726
Constant		α_{21}	-0.14217			β_{21}	0.04077	γ_{21}	-0.0111
α_0	14.09033	α_{22}	0.14217			β_{22}	-0.17867	γ_{22}	0.01109

Table 3. 1996-2002 Efficiency Score and Shadow Price for Regions in China

			1996		1997		1998		1999		2000		2001		2002	
No.	Region	Area	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price
1	Beijing	E	0.663	0.518	0.690	0.520	0.678	0.524	0.641	0.530	0.657	0.533	0.645	0.542	0.616	0.547
2	Tianjin	E	0.735	0.511	0.781	0.511	0.742	0.514	0.686	0.519	0.792	0.512	0.733	0.516	0.754	0.517
3	Hebei	E	0.977	0.503	1.000	0.504	1.000	0.503	0.913	0.504	0.926	0.504	0.862	0.505	0.851	0.506
4	Shanxi	C	0.858	0.503	0.893	0.503	1.000	0.502	0.868	0.503	0.863	0.503	0.819	0.503	0.836	0.503
5	Inner Mongolia	C	0.959	0.503	0.952	0.503	0.943	0.503	0.862	0.504	0.863	0.504	0.800	0.504	0.848	0.504
6	Liaoning	E	0.701	0.514	0.744	0.515	0.768	0.518	0.762	0.519	0.767	0.520	0.725	0.524	0.728	0.526
7	Jilin	C	0.725	0.509	0.735	0.510	0.740	0.510	0.707	0.510	0.712	0.511	0.681	0.513	0.659	0.514
8	Heilongjiang	C	0.837	0.512	0.855	0.513	0.769	0.514	0.718	0.515	0.753	0.515	0.709	0.517	0.708	0.519
9	Shanghai	E	0.950	0.515	0.991	0.518	1.000	0.521	0.946	0.527	0.988	0.526	0.949	0.531	0.967	0.530
10	Jiangsu	E	0.880	0.508	0.914	0.510	0.972	0.509	0.886	0.512	0.968	0.510	0.957	0.512	0.997	0.513
11	Zhejiang	E	0.772	0.512	0.801	0.514	0.841	0.510	0.817	0.511	0.816	0.512	0.789	0.514	0.839	0.514
12	Anhui	C	0.593	0.508	0.607	0.509	0.578	0.508	0.534	0.509	0.508	0.510	0.474	0.511	0.473	0.512
13	Fujian	E	0.988	0.516	1.000	0.523	0.924	0.519	0.861	0.520	0.888	0.516	0.776	0.522	0.765	0.524
14	Jiangxi	C	0.628	0.507	0.620	0.510	0.615	0.509	0.577	0.510	0.579	0.508	0.596	0.511	0.484	0.512
15	Shandong	E	0.945	0.504	0.960	0.505	0.998	0.505	0.902	0.506	0.925	0.506	0.899	0.508	0.916	0.508
16	Hennan	C	0.549	0.508	0.602	0.507	0.589	0.507	0.526	0.508	0.528	0.507	0.516	0.508	0.533	0.509
17	Hubei	C	0.720	0.509	0.759	0.510	0.771	0.508	0.730	0.509	0.754	0.509	0.711	0.511	0.698	0.512

18	Hunan	C	0.748	0.505	0.747	0.506	0.751	0.505	0.701	0.505	0.724	0.505	0.647	0.506	0.635	0.507
19	Guangdong	E	0.891	0.512	0.910	0.515	0.939	0.512	0.910	0.513	0.994	0.510	0.969	0.511	1.000	0.512
20	Guangxi	E	0.915	0.503	0.951	0.504	0.872	0.503	0.755	0.504	0.831	0.502	0.708	0.503	0.690	0.504
21	Hainan	E	0.754	0.528	0.741	0.540	0.682	0.536	0.633	0.534	0.194	0.543	0.551	0.544	0.553	0.541
22	Sichuan	W	0.641	0.504	0.633	0.504	0.622	0.504	0.616	0.503	0.683	0.503	0.621	0.504	0.564	0.504
23	Guizhou	W	0.843	0.502	0.836	0.502	0.879	0.501	0.745	0.502	0.714	0.502	0.607	0.503	0.592	0.503
24	Yunnan	W	0.708	0.506	0.701	0.507	0.671	0.506	0.595	0.507	0.601	0.506	0.520	0.508	0.507	0.509
25	Tibet	W	0.377	0.604	0.539	0.727	0.289	0.654	0.834	0.703	0.910	0.727	0.919	0.744	1.000	0.754
26	Shaanxi	W	0.643	0.504	0.638	0.504	0.606	0.505	0.597	0.505	0.594	0.505	0.571	0.506	0.565	0.506
27	Gansu	W	0.694	0.504	0.696	0.504	0.651	0.504	0.572	0.506	0.597	0.505	0.558	0.505	0.570	0.505
28	Qinghai	W	0.703	0.521	0.716	0.516	0.657	0.522	0.604	0.524	0.619	0.523	0.561	0.522	0.555	0.526
29	Ningxia	W	1.000	0.502	0.999	0.502	0.928	0.503	0.838	0.503	0.839	0.503	0.748	0.503	0.752	0.503
30	Xinjiang	W	0.771	0.508	0.788	0.510	0.757	0.509	0.712	0.509	0.744	0.510	0.678	0.511	0.660	0.512
	Area Average	E	0.848	0.512	0.874	0.515	0.868	0.514	0.809	0.517	0.812	0.516	0.797	0.519	0.806	0.520
		C	0.735	0.507	0.752	0.508	0.751	0.507	0.691	0.508	0.698	0.508	0.662	0.509	0.653	0.510
		W	0.709	0.517	0.727	0.531	0.673	0.523	0.679	0.529	0.700	0.531	0.643	0.534	0.641	0.536

Note: The unit of the shadow price is 100 million RMB in 1996 prices.

Table 4. 1996-2002 Efficiency Score and Shadow Price in Acid Rain Regions

			1996		1997		1998		1999		2000		2001		2002	
No.	Region	Area	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price	Efficiency	Shadow Price
10	Jiangsu	E	0.880	0.508	0.914	0.510	0.972	0.509	0.886	0.512	0.968	0.510	0.957	0.512	0.997	0.513
11	Zhejiang	E	0.772	0.512	0.801	0.514	0.841	0.510	0.817	0.511	0.816	0.512	0.789	0.514	0.839	0.514
14	Jiangxi	C	0.628	0.507	0.620	0.510	0.615	0.509	0.577	0.510	0.579	0.508	0.596	0.511	0.484	0.512
17	Hubei	C	0.720	0.509	0.759	0.510	0.771	0.508	0.730	0.509	0.754	0.509	0.711	0.511	0.698	0.512
18	Hunan	C	0.748	0.505	0.747	0.506	0.751	0.505	0.701	0.505	0.724	0.505	0.647	0.506	0.635	0.507
19	Guangdong	E	0.891	0.512	0.910	0.515	0.939	0.512	0.910	0.513	0.994	0.510	0.969	0.511	1.000	0.512
20	Guangxi	E	0.915	0.503	0.951	0.504	0.872	0.503	0.755	0.504	0.831	0.502	0.708	0.503	0.690	0.504
22	Sichuan	W	0.641	0.504	0.633	0.504	0.622	0.504	0.616	0.503	0.683	0.503	0.621	0.504	0.564	0.504
23	Guizhou	W	0.843	0.502	0.836	0.502	0.879	0.501	0.745	0.502	0.714	0.502	0.607	0.503	0.592	0.503
Average			0.782	0.507	0.797	0.508	0.807	0.507	0.748	0.508	0.785	0.507	0.734	0.508	0.722	0.509
China Average			0.764	0.512	0.784	0.518	0.764	0.515	0.727	0.518	0.737	0.519	0.700	0.521	0.700	0.522
Area Average		E	0.848	0.512	0.874	0.515	0.868	0.514	0.809	0.517	0.812	0.516	0.797	0.519	0.806	0.520
		C	0.735	0.507	0.752	0.508	0.751	0.507	0.691	0.508	0.698	0.508	0.662	0.509	0.653	0.510
		W	0.709	0.517	0.727	0.531	0.673	0.523	0.679	0.529	0.700	0.531	0.643	0.534	0.641	0.536

Table 5. Kruskal-Wallis Test of the Shadow Prices of SO_2 during the Years

Period	Mean	Chi-square	P value
1996	0.512	4.460	0.615
1997	0.518		
1998	0.515		
1999	0.518		
2000	0.519		
2001	0.521		
2002	0.522		

Table 6. Kruskal-Wallis Test of the Shadow Prices in Areas

Area	Mean	Chi-square	P value
East area	0.516	28.922	<0.001***
Central area	0.508		
West area	0.529		

Note: *** represents significance at the 1% level.

Table 7. Multiple Comparison of Kruskal-Wallis Test of the Shadow Prices in Areas

Regions	P value
East v. Central	<0.001***
East v. West	<0.001***
West v. Central	0.121

Note: *** represents significance at the 1% level.