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A water resource efficiency analysis of the Chinese industrial sector

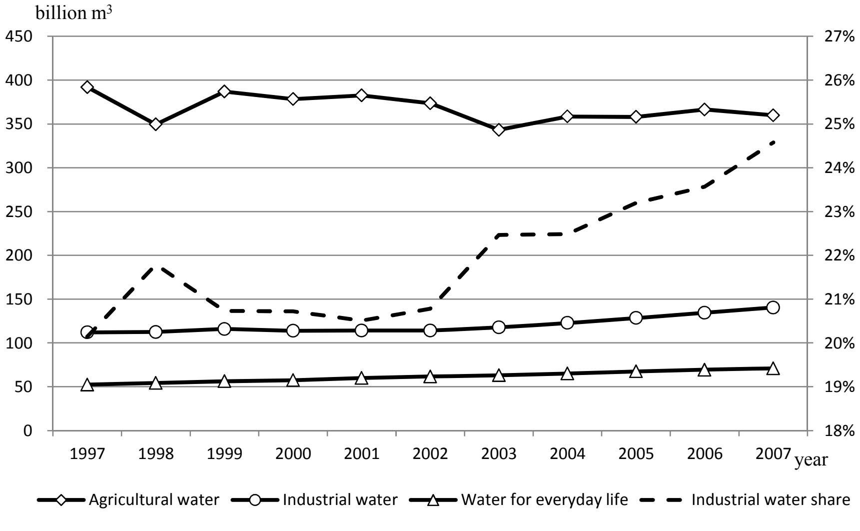
Abstract

Industrial water consumption is increasing in China. The amount of industrial water use increased 28.3 billion m^3 from 1997 to 2007, and the share of industrial water use in China rose from 20% to 24%. In addition China has diversity of water resource. Specifically the northern part of China faces a serious water shortage problem. Furthermore, each province has different characteristics of industry type. Sales and value added by using one unit of water input are different among industries. For sustainable development in China, an allocation strategy of limited water resource is important. The objective of this study is to clarify the efficiency of water usage in the Chinese industrial sector. The authors also estimate the shadow prices of fresh water and wastewater in each industry. The research period is from 1996 to 2007. The authors find that most of the provinces that were evaluated as efficient at reducing fresh water usage and wastewater discharge are located in the northern part of China. The results imply that in the Hebei, Shanxi, Ningxia, and Guizhou provinces, the policies that provide incentives for the industrial sector to achieve water use efficiency improvement are more effective than the policies that address the restriction of waste water discharge. The shadow prices and inefficiencies differed among distinct provinces and business types. Therefore, to establish the appropriate environmental and water price policies, the Chinese government must consider the differences that exist among the provinces and industries of China.

Keywords: productive inefficiency, shadow price, fresh water use, industrial wastewater, China.
JEL Classification: Q53, Q25, Q56, Q57, O47.

Introduction

Water resource use in China. The Chinese economy has continued to grow and develop. The average annual economic growth rate in China between 1979 and 2009 was 9.93%, and this rapid economic growth is projected to continue (Ying and Ishiyama, 2011). This growth has caused environmental problems that are becoming more serious with each passing year (Chow, 2011). In particular, the issue of water resource shortages poses a significant concern in China because the quantity of Chinese water resources per capita is only one fourth of the world average. In addition, various portions of China have diverse water resource availability; specifically, the northern part of China faces a serious water resource shortage problem. China's 11th Five-Year Plan, which was published in 2006, incorporated initiatives by the Chinese government that sought to solve this water shortage problem. According to the 2007 China Water Resources Bulletin, the total water use in China in 2007 was 581.87 billion m^3. This water usage included the following contributions: the agricultural water use was 359.85 m^3 (60%), the industrial water use was 140.41 m^3 (24%) and the water that was used for everyday living was 71.04 m^3 (12%). Figure 1 illustrates the amount of water that was used from 1997 to 2007 in China by sector.



Source: China Water Resources Bulletin (CWRB).

Fig. 1. The water use by sector in China

This figure indicates that agricultural water usage generally decreased during this period, whereas the consumption of water for industrial uses and for everyday living increased during this time. The amount of industrial water that was used grew rapidly after 2002, and the share of industrial water usage increased from 20% to 24%. This rapid growth in industrial water consumption has placed additional pressure on the issue of Chinese water resource shortages.

Industrial sector development is the main driver of China's rapid economic growth (Li and An, 2004). Therefore, China must appropriately manage its water resources, particularly its industrial water, to achieve sustainable development. In the remainder of this paper, we focus on water resource management in the Chinese industrial sector. In the following section, we summarize the characteristics of water resource consumption and waste water discharge by region and business type.

The characteristics of industrial water use by business type. The characteristics of water resource usage and waste water discharge differ for various business types in the industrial sector of China. Table 1 provides fresh water use data, waste water discharge data, and simple efficiency indices for the Chinese industrial sector[1].

Table 1. Water use indices in the Chinese industrial sector in 2006

	Fresh water use [10,000 tonnes]	GDP/ Fresh water use (adj) [yuan / ton]	Waste water discharge [10,000 tonnes]	GDP / Waste water discharge (adj) [yuan / ton]	Recycled water use ratio [%]
Mining	57,285	313.2	54,023	332.1	64%
Food	57,124	117.4	43,113	155.6	67%
Beverage	77,083	137.6	56,049	189.3	56%
Spinning	233,510	64.8	197,934	76.4	29%
Paper	440,076	18.1	374,407	21.2	51%
Printing	1,539	623.4	1,199	800.2	56%
Oil refining	120,765	162.4	70,281	279.0	94%
Chemical product	493,044	62.3	335,956	91.4	88%
Medicinal product	64,128	142.2	42,988	212.1	74%
Chemical fiber	62,449	53.2	49,543	67.0	88%
Non-metallic minerals	81,429	187.0	43,070	353.5	68%
Steel	386,088	127.4	156,727	313.7	92%
Non-ferrous metal	42,680	397.5	32,751	518.0	89%
Metal	27,298	399.7	22,448	486.1	66%
Machine	16,461	963.2	12,530	1,265.4	57%
Transportation	34,880	739.1	25,708	1,002.8	72%
Electric product	30,977	513.0	23,905	664.7	74%
Electric device	9,989	940.8	7,845	1,197.9	73%
Electricity, hot water, steam supply	3,600,374	6.5	217,145	107.8	78%

Sources: China Industrial Economical Statistical Yearbook 2007, China Environmental Yearbook 2007.

We can observe that six industries, namely, the spinning, paper, oil refining, chemical, steel and electricity/hot water/steam industries, consumed a high quantity of the fresh water resources that were used in 2006. In particular, these six industries accounted for 84.6% of the total fresh water usage in the industrial sector. In this paper, we refer to these six industries as fresh water oriented industries. Fresh water oriented industries require a great deal of water resources for their businesses; however, the GDP that was produced for each unit of fresh water that was used was lower for these industries than for other Chinese industries.

The characteristics of waste water discharge also differ for various types of businesses. Fresh water oriented industries discharge huge quantities of wastewater. However, the GDP that was generated for eachunit of waste water that was discharged was higher for the oil refining and steel industries compared with the other freshwater oriented industries. One interpretation for this observation is that these two industries use a great deal of filtered waste water for boiler and cooling water. The recycled water use ratios (recycled water use / total industrial water

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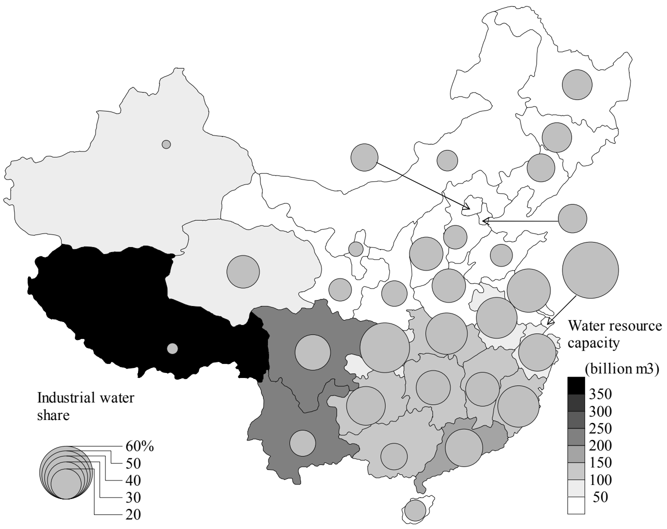
[1] We use the China Environmental Yearbook (CEY) and the China Industrial Economic Statistical Yearbook (CIESY) to calculate the simple efficiency indices in Table 1. The CIESY data are gathered from the entirety of China, whereas the CEY data are estimated through sample surveys. Therefore, we use sales values, which both datasets possess, as an adjustment parameter for expanding the CEY data. We include the "adj" designation for environmental data that were expanded.

use) in the oil refining and steel industries are 94% and 92%, respectively. By contrast, the spinning and paper product industries use water resources for the process of washing products, which produces increasingly polluted wastewater. Because the cost of using recycled water is expensive, the recycled water use ratio remains at a low level. In particular, the recycled water use ratio of the spinning industry was only 29%, which is remarkably low.

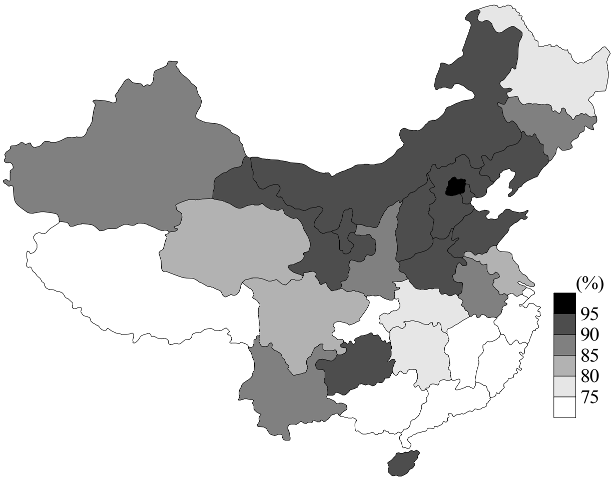
The characteristics of industrial water use by region. We next discuss the regional characteristics of industrial water use. The different regions of China have diverse water resources. In particular, the northern part of China faces the most serious water resource shortage problems (Figure2). In addition, the share of industrial water usage was highest in coastal areas and in the southern portions of inland Chinese regions.



Source: China Statistical Yearbook 2008.

Fig. 2. The water resource capacities and industrial water consumption shares for China in 2007

We consider the recycled water use ratio in the industrial sector by province (Figure 3). Figure 3 demonstrates that northern provinces achieve demonstrably higher recycled water use ratios than southern provinces. Beijing and Tianjin, which obtain their water supplies from the Yellow River, achieved recycled water use ratios of greater than 90%. By contrast, southern provinces such as Shanghai and Guangdong have recycled water use ratios that are below 75%.



Source: China Statistical Yearbook 2008.

Fig. 3. The recycled water use ratios in the Chinese industrial sector in 2007

What are the incentives for manufacturing companies to increase their recycled water use ratios? Companies certainly attempt to achieve the targets that have been established by the government to improve water use efficiency. However, these attempts are not the result of voluntary efforts on the part of the top-level managers of these companies. In this paper, we note two reasons for this phenomenon. One of these reasons is that although companies benefit from reducing the material costs of the water resources that they use (e.g., by incurring reduced tap water fees), as many previous studies have observed, Chinese industrial water is provided at a low fixed price; this low price reduces the companies'incentives to decrease their water usage. The second reason for the aforementioned phenomenon is the opportunity cost that results if the Chinese government restricts industrial water use. If manufacturing plants do not use sufficient water resources, they will need to decrease their factory operating ratios. To prepare and manage the potential risks of a water resource shortage, companies may increase their recycled water use ratios and attempt to decrease their fresh water dependencies by utilizing modern equipment and improving their production processes. However, the southern provinces of China, which have abundant water resources, are unlikely to encounter governmental restrictions on industrial water use. In addition, the price of industrial water is low in these provinces. Therefore, companies in southern provinces have few incentives to raise their recycled water use ratios through additional investments.

1. Objective

There are two ways of conserving water resources in the industrial sector. One of these methods is to improve overall water use efficiency, and the other method of saving water resourcesis to increase recycled water use ratios. Many studies have been conducted on Chinese industrial water resource issues. However, there are few studies that treat fresh water and recycled water separately for productivity analyses. To improve water resource efficiency, it is important to clarify the factors that cause the inefficiencies that are observed.

In addition, the water resource use efficiency of the industrial sector primarily depends on both business structures and regional characteristics. Therefore, the objective of this study is to clearly assess water use efficiency in the Chinese industrial sector, focusing on the characteristic of industry type. We also estimate the shadow prices of fresh water and wastewater in each industry. The ultimate goal of this research is to provide policy recommendations for appropriate water resource allocations in the Chinese industrial sector that can ensure sustainable development. The primary decision-making factors for determining plant locations are the transfer costs and the market demand capacities. Because of these factors, we suggest that industrial business locations in China should be designed to save water resources and achieve sustainable economic growth.

2. Methodology

This study is composed of two primary aspects. One of these aspects is an efficiency evaluation of water resource usage by provincial industrial sectors that include a mix of different types of businesses. In this analysis, we separately assess fresh water and recycled water data. Second, we estimate the shadow prices of fresh water and waste water in six fresh water oriented industries. Based on the results of these two analyses, we discuss appropriate industrial sector design.

2.1. Directional distance function (DDF). We apply the directional distance function (DDF) approach to evaluate water use efficiency and shadow prices. As an extension of nonparametric production function approaches, DDF can not only consider conventional market inputs and outputs, such as labor, capital, and production, but also consistently identify undesirable output. In the published literature, there are an increasing number of methodologies for measuring productivity efficiency that incorporate environmental factor considerations (Chambers, Chung, and Färe, 1996; Chung, Färe, and Grosskopf, 1997; Boyd and McClelland, 1999; Hailu and Veeman, 2000; Zofio and Prieto, 2001; Boyd, Tolley, and Pang, 2002; Domazlicky and Weber, 2004; Picazo-Tadeo, Reig-Martínez, and Hernández-Sancho, 2005; Managi, Opaluch, Jin, and Grigalunas, 2005; Piot-Lepetit and Moing, 2007; Murty, Kumar and Dhavala, 2007; Watanabe and Tanaka, 2007).

Let $x \in \Re_{+}^{L}, b \in \Re_{+}^{R}$, and $y \in \Re_{+}^{M}$ be the vectors for inputs, environmental outputs (or undesirable outputs) and market outputs (or desirable output), respectively. The production technology can then be defined as follows:

$$P(x) = \{(x, y, b) : x \text{ can produce} (y, b)\} \tag{1}$$

We assume that the good and bad outputs are joint-null because a company cannot produce desirable outputs without also producing undesirable outputs (Shephard and Färe, 1974).

The inefficiency $D(x, y, b| g_x, g_y, g_b)$ of production units in $P(x)$ for each province in this study is defined in terms of the distance β from the production frontier that consists of efficient production units, as follows:

$$\vec{D}(x, y, b | g_x, g_y, g_b) = \mathrm{Sup}\{\beta : (\beta + \beta g_y, b - \beta g_b)\} \in P(x - \beta g_x) \tag{2}$$

where g_x, g_y and g_b denote the non-negative directional vectors of the input, desirable and undesirable outputs, respectively. Using the above definition, equation (3) may be obtained:

$(y, b) \in \mathrm{P}(x)$ if and only if

$$D(x, y, b| g_{x,} g_{y,} g_b) \geq 0. \tag{3}$$

To further define the directional vectors in a productivity analysis that considers undesirable outputs, either weak disposability or strong disposability must be assumed. Weak disposability is applicable if an undesirable output is restricted by environmental standards and laws (Färe and Primont, 1995). Under these conditions, companies must pay opportunity costs to manage undesirable outputs. By contrast, strong disposability is applicable if companies do not need to pay any costs to address undesirable output emissions because these emissions are not regulated.

For the situation involving the reduction of waste water discharge from manufacturing plants, the strong disposability assumption is considered to be inappropriate, but the assumption of weak disposability is more applicable. Under the weak disposability assumption, equation (2) can be computed for province k by solving the following optimization problem:

$$\vec{D}\left(x_k^l, y_k^m, b_k^r \mid g_{x^l}, g_{y^m}, g_{b^r}\right) = \text{Maximized } \beta_k, \tag{4}$$

$$s.t. \sum_{i=1}^{N} \lambda_i x_i^l \le x_k^l - \beta_k g_{x^l}, \tag{5}$$

$$\sum_{i=1}^{N} \lambda_i y_i^m \le y_k^m - \beta_k g_{y^m}, \tag{6}$$

$$\sum_{i=1}^{N} \lambda_i b_i^r = b_k^r - \beta_k g_{b^r}, \tag{7}$$

$$\sum_{i=1}^{N} \lambda_i = 1, \tag{8}$$

$$\lambda_i \ge 0 \qquad (i = 1, \ldots N), \tag{9}$$

where l, m, and r represent the names of the input, desirable output, and undesirable output, respectively. In the above equations, x is an input matrix with dimensions $L \times N$, y is a desirable-output matrix with dimensions $M \times N$, and b is an undesirable-output matrix with dimensions $R \times N$. Furthermore, g_x is the directional vector of the input matrix, g_y is the directional vector of the desirable-output matrix, g_b is the directional vector of the undesirable-output matrix, β_k is the inefficiency score of the firm k, and λ_i is the weight variable. To estimate the inefficiency score of all of the examined firms, the model must be independently applied to each of the N firms that are considered in this study. The right sides of equations (5), (6) and (7) represent the frontier line, and λ_i is the parameter that is used to determine the reference point. The directional vector specifies the means by which inefficient firms can improve productivity to approachthe frontier production line. Equation (8) establishes the production function under various return-to-scale assumptions.

2.2. Shadow price estimation. The economic valuation method for using the DDF as a nonparametric approach to handle environmentally undesirable outputs was developed by Boyd, Molburg, and Prince (1996) and Lee, Park, and Kim (2002). In accordance with Lee, Park, and Kim (2002), we can use the following measurement to estimate q, the economic value of an environmentally undesirable output:

$$q = p \times \frac{\partial \vec{D}\left(x, y^*, b^*\right) / \partial b^*}{\partial \vec{D}\left(x, y^*, b^*\right) / \partial y^*} \times \frac{\sigma_b}{\sigma_y}, \tag{10}$$

where, (y^*, b^*) is the intersection point between the directional vector of an inefficient province and the frontier curve. The inefficiency factors σ_b and σ_y are defined as follows:

$$\sigma_b = \frac{1}{1 - \vec{D}(x, y, b)\dfrac{g_b}{b^*}} \text{ and } \sigma_y = \frac{1}{1 - \vec{D}(x, y, b)\dfrac{g_b}{b^*}}. \tag{11}$$

In equation (10), the economic value of the market output can be normalized to $p = 1$; thus, the economic value q is considered to be the value of an environmentally undesirable good relative to the value of the market output. The shadow price in this study is derived from a production frontier analysis that does not consider either shifts in the frontier or any future technological innovations. Therefore, the reduction potential is measured with respect to the best practices and technology that are currently available in China.

2.3. The DDF model for shadow price estimation. We establish two models for estimating shadow prices, namely, the *fresh water model* and the *waste water model*. The differences between these two models provide a method of determining the directional vector. The *fresh water model* can be described as follows:

$$\vec{D}\left(x_k, f_k, y_k, \mid 0, f_i, 0\right) = \text{Maximized } \beta_k, \tag{12}$$

$$s.t. \sum_{i=1}^{N} \lambda_i x_i^l \le x_k^l, \tag{13}$$

$$\sum_{i=1}^{N} \lambda_i f_i \le \left(1 - \beta_k\right) f_k, \tag{14}$$

$$\sum_{i=1}^{N} \lambda_i y_i^m \ge y_k^m, \tag{15}$$

$$\sum_{i=1}^{N} \lambda_i = 1, \tag{16}$$

$$\lambda_i \ge 0 \qquad (i = 1, \ldots N). \tag{17}$$

The *waste water model* can be described as follows:

$$\vec{D}\left(x_k, y_k, w_k \mid 0, 0, w_i\right) = \text{Maximized } \beta_k, \tag{18}$$

$$s.t. \sum_{i=1}^{N} \lambda_i x_i^l \le x_k^l, \tag{19}$$

$$\sum_{i=1}^{N} \lambda_i y_i^m \ge y_k^m, \tag{20}$$

$$\sum_{i=1}^{N} \lambda_i w_i = \left(1 - \beta_k\right) w_k, \tag{21}$$

$$\sum_{i=1}^{N} \lambda_i = 1, \tag{22}$$

$$\lambda_i \ge 0 \qquad (i = 1, \ldots N), \tag{23}$$

where x is the marketable input, f is the fresh water use, y is the desirable output, and w is the waste water discharge. The fresh water model can estimate fresh water use inefficiency, which is defined as the percentage by which a company can reduce its fresh water consumption without increasing its input or decreasing its output. The *waste water model* can calculate waste water discharge inefficiency, which is defined as the percentage by which acompany can reduce its waste water discharge without increasing its input or decreasing its output.

2.4. The water use efficiency evaluation model. We define two water efficiency evaluation models which are the water use *efficiency improvement model* and the *substitution model*. Table 2 indicates the assumptions of each model. We incorporate the assumptions that are represented in Table 2 into the DDF approach.

Table 2. The assumptions of each model

Model	Scenario	Total industrial water use	Wastewater discharge	Fresh water use	Recycled water use	Recycled water use ratio
Efficiency improvement model	1. Improvements in the total water use efficiencies 2. Recycled water use ratio is stable	Decrease	Decrease	Decrease	No restriction	Stable
Substitution model	1. Improvements in the recycled water use ratios 2. Recycled water is used to substitute for fresh water	Constant	Decrease	Decrease	Increase	Increase

The *efficiency improvement model* can be described as follows:

$$\vec{D}\left(x_k^l, f_k, r_k, y_k^m, w_k \mid 0, f_i, r_i, 0, w_i\right) = \text{Maximized}\,\beta_k, \quad (24)$$

$$s.t. \sum_{i=1}^{N} \lambda_i y_i \geq y_k, \quad (25)$$

$$s.t. \sum_{i=1}^{N} \lambda_i x_i \leq x_k, \quad (26)$$

$$\sum_{i=1}^{N} \lambda_i f_i \leq f_k \left(1-\beta_k\right), \quad (27)$$

$$\sum_{i=1}^{N} \lambda_i w_i = w_k \left(1-\beta_k\right), \quad (28)$$

$$\sum_{i=1}^{N} \lambda_i = 1, \quad (29)$$

$$\lambda_i \geq 0 \qquad (i = 1, \ldots N), \quad (30)$$

where x is the marketable input, f is the fresh water use, r is the recycled water use, y is the desirable output, and w is the waste water discharge. The *efficiency improvement model* can estimate how much a company can reduce its fresh water use, recycled water consumption and waste water discharge without increasing its input or decreasing its output.

The *substitution model* can be used to estimate the degree to which a company can substitute recycled water for its fresh water uses. The upper limit of recycled water usage is dependent on the labor force, capital input, fresh water quantity and waste water quantity that are being considered. The *substitution model* can be described as follows:

$$\vec{D}\left(x_k^l, f_k, r_k, y_k^m, w_k \mid 0, f_i, r_i, 0, w_i\right) = \text{Maximized}\,\beta_k, \quad (31)$$

$$s.t. \sum_{i=1}^{N} \lambda_i y_i \geq y_k, \quad (32)$$

$$s.t. \sum_{i=1}^{N} \lambda_i x_i \leq x_k, \quad (33)$$

$$\sum_{i=1}^{N} \lambda_i f_i \leq f_k - \beta_k, \quad (34)$$

$$\sum_{i=1}^{N} \lambda_i r_i \geq r_k + \beta_k, \quad (35)$$

$$\sum_{i=1}^{N} \lambda_i w_i = w_k - \beta_k, \quad (36)$$

$$\sum_{i=1}^{N} \lambda_i = 1, \quad (37)$$

$$\lambda_i \geq 0 \qquad (i = 1, \ldots N). \quad (38)$$

3. Data

The data for the study were primarily collected from two sources: the China Environmental Statistical Yearbook (CES) and the China Economy and Industry Statistical Yearbook (CEIS). The data, which are organized by industry, span the twelve years between 1996 and 2007[1]. The main variables that were used in the analysis are the value of desirable output that was added (in yuan); the amount of labor (in number of persons) and the net value of fixed assets (in yuan), which were the market inputs; the fresh water use (in tonnes) and the recycled water use (in tonnes), which were the environmental inputs; and the wastewater discharge amount (in tonnes), which was the undesirable output. We calculate the water use efficiency by applying the *efficiency improvement model* and the substitution model. For these two models, we use data for 31 provinces. We use two separate datasets in the shadow price estimation model. One of these datasets is the data for 31 provinces, which are used to consider regional shadow price differences. The other dataset is the time series dataset for fresh water oriented industries throughout the entirety of China. We use these time series data to discuss the shadow price changes of each fresh water oriented industry.

4. Results and discussion

4.1. The results of provincial analyses. In this section, we discuss the results of the *efficiency improvement model* and the *substitution model*; these results are organized by province. Inefficient provinces are able to reduce their fresh water and waste water usage

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[1] Fresh water use data by industry are available only between 1996 and 2006. Therefore, we apply the shadow price estimation model from 1996 to 2006.

without decreasing their marketable output by implementing the technology and industrial structure of efficient provinces. The inefficiency scores that are generated by the *efficiency improvement model*, which are illustrated in Figure 4, represent the reductions that could be implemented in the ratios of fresh water usage and wastewater discharge without adversely affecting productivity (e.g., a value of 0.7 indicates that a 70% reduction in fresh water use can be implemented without increasing marketable inputs or decreasing marketable outputs). As shown in Figure 4, many Northern provinces were considered to be efficient by the standards of the *efficiency improvement model*. The Hebei and Shanxi provinces were evaluated as inefficient regions, despite the fact that the locations of these provinces are the North and Yellow river basins, respectively. One explanation of this result is that the mining sector is one of the major industries in Shanxi; the mining industry typically produces large quantities of waste water discharges that are polluted by the washing of coal and therefore requires huge inputs of industrial water.

The results of the *substitution model* indicate the amounts of fresh water that could be replaced with recycled water (in thousands of tonnes). According to the results of the substitution model, Northern provinces were considered to be more efficient than southern provinces. The results of the substitution model were similar to the *efficiency improvement model* results for many provinces, although several provinces demonstrated different results for these two models. For example, the Hebei province was considered to be inefficient by the *efficiency improvement model*, despite the fact that this province was considered to be efficient by the *substitution model*. This difference occurred because this province appeared to have the ability to reduce its fresh water inputs through the use of recycled water as a substitute. One interpretation of this phenomenon is that the steel industry, which is one of the major industries in Hebei, requires huge quantities of fresh water and demonstrates a significant ability to increase its use of recycled water. The steel industry in Hebei produces 25% of all of the steel that is manufactured in China. The provinces that were considered to be inefficient in the *efficiency improvement model* but efficient in the *substitution model* are the Hebei, Shanxi, Ningxia and Guizhou provinces. These provinces have already achieved high levels of recycled water usage technologies. Therefore, the policies that provide incentives for the industrial sector to achieve water use efficiency improvement are effective in these provinces.

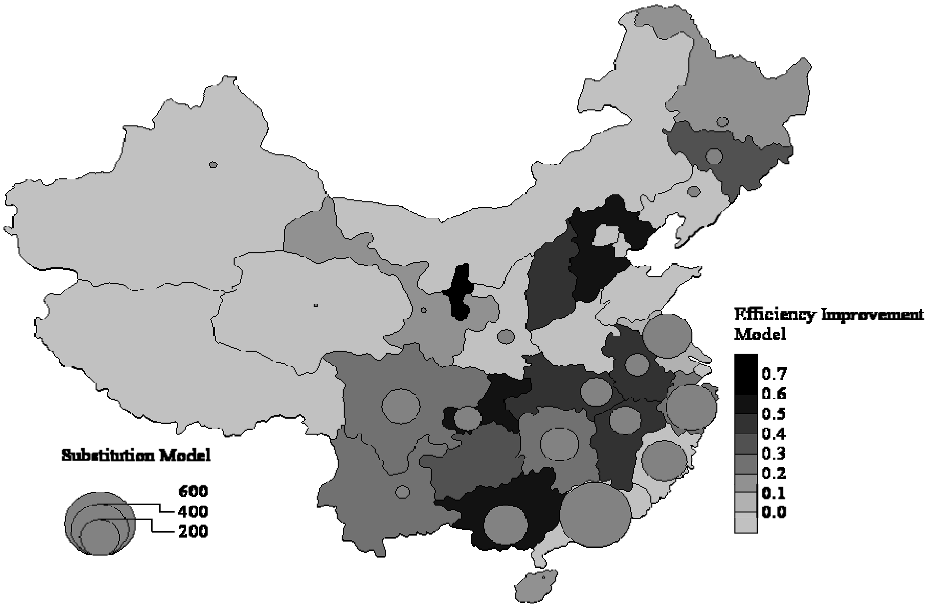

Fig. 4. The results of the efficiency improvement model and the substitution model in 2007

Figure 5 illustrates the 2007 shadow prices of fresh water, as calculated by the *fresh water model*, and Figure 6 indicates the 2007 shadow prices of wastewater, as calculated by the *wastewater model*. As shown in Figure 5, the shadow prices of southern provinces tend to be lower than the shadow prices of Northern provinces. This result implies that the economic benefits that are lost from the production scale decreases that would be involved in saving one unit of fresh water are relatively lower for the southern provinces than the Northern provinces. By comparing Figures 5 and 6, it can be observed that the gap between northern and southern provinces is greater for the shadow prices of wastewater than for the shadow prices of fresh water. In particular, the shadow price of wastewater in Beijing was much more expensive than the shadow prices of wastewater in southern provinces, a result that demonstrates that wastewater discharge restrictions may reduce the financial performance of companies. In the Ningxia, Hebei, and Jiangsu provinces, which have low shadow prices for fresh water and high shadow prices for wastewater, it may be difficult to reduce wastewater discharge, whereas a policy for fresh water use efficiency improvement may be amore effective approach for the conservation of water resources. By contrast, wastewater discharge restrictions may be effective at improving the recycled water use ratio in the Heilongjiang and Chongqing provinces, which have high shadow prices for fresh water and low shadow prices for wastewater.

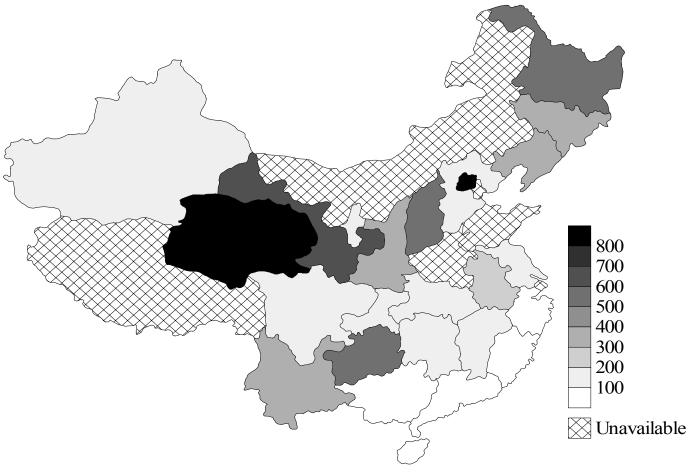

Fig. 5. The shadow prices of fresh water in the Chinese industrial sector by province in 2007 (yuan/m^3)

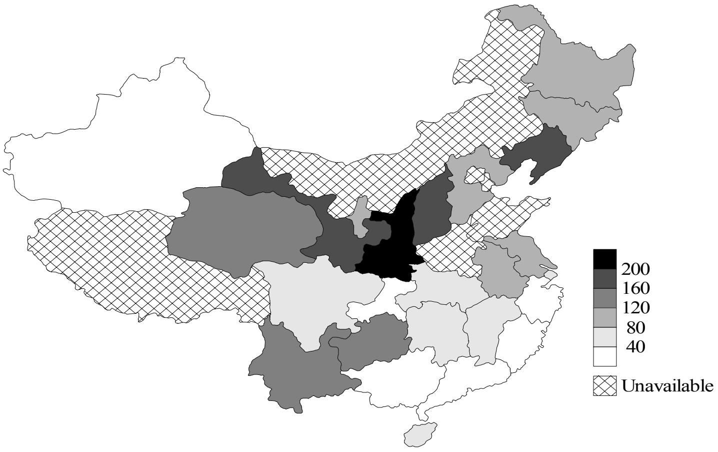

Fig. 6. The shadow prices of wastewater in the Chinese industrial sector by province in 2007 (yuan/m^3)

4.2. The results of time series analyses of six industries. In this section, we discuss the shadow prices and inefficiency scores of fresh water oriented industries from 1996 to 2006. Because the CIESY was not published in 2005, we could not incorporate data from 2004 into our dataset; therefore, we removed the 2004 sample from our dataset.

Table 3 and Table 4 indicate the inefficiency scores and shadow prices of the *fresh water model* and the*waste water model*, respectively. As shown in Table 3, the inefficiency scores of the*fresh water model* tend to improve every year for each industry except for oil refining. One interpretation of the result for the oil refining industry is the rapid oil price changes that have been caused by the recent Iraq war. Shadow prices quickly increased in the paper, chemical and steel industries from 1996 to 2006; in particular, shadow prices in the chemical industry increased by more than threefold during this time. Comparing the results for each industry, we find that the shadow prices of the spinning and oil refining industries were relatively high, whereas the shadow prices of the paper and electricity industries were relatively low. This result implies that the strategy that maximizes the value of the fresh water that is used involves shifting the allocation of fresh water from the paper and electricity industries to the spinning and oil refining industries.

Table 3. The productive inefficiency scores with respect to fresh water use and the shadow prices of fresh water for the examined industries

	Inefficiency score						Shadow price of fresh water (yuan/m^3)					
	Spinning	Paper	Oil	Chemical	Steel	Power	Spinning	Paper	Oil	Chemical	Steel	Power
1996	0.31	0.66	0.18	0.80	0.84	0.25	43.7	7.3	135.6	12.1	20.0	4.7
1997	0.25	0.69	0.29	0.76	0.83	0.49	47.6	5.8	116.4	14.9	21.2	3.2

Table 3 (cont.). The productive inefficiency scores with respect to fresh water use and the shadow prices of fresh water for the examined industries

	Inefficiency score						Shadow price of fresh water (yuan/m^3)					
	Spinning	Paper	Oil	Chemical	Steel	Power	Spinning	Paper	Oil	Chemical	Steel	Power
1998	0.21	0.64	0.34	0.75	0.82	0.23	50.4	7.8	109.0	15.6	21.6	4.9
1999	0.10	0.55	0.75	0.67	0.79	0.32	57.1	10.4	41.3	20.5	25.6	4.3
2000	0.12	0.52	0.74	0.58	0.74	0.26	55.7	10.2	43.0	26.0	31.5	4.7
2001	0.19	0.51	0.09	0.63	0.70	0.32	51.2	9.3	150.7	22.8	37.2	4.3
2002	0.20	0.43	0.06	0.50	0.58	0.13	50.8	10.3	154.3	30.9	51.9	6.3
2003	0.11	0.29	0.57	0.32	0.68	0.14	56.5	12.8	71.1	42.3	39.8	5.5
2004	-	-	-	-	-	-	-	-	-	-	-	-
2005	0.05	0.16	0.00	0.00	0.00	0.36	60.5	15.1	-	-	-	4.0
2006	0.00	0.00	0.18	0.00	0.00	0.00	-	-	135.0	-	-	-

However, the electricity industry serves the important function of supplying power to other manufacturing industries; therefore, reductions in the operation ratios of electricity plants for the purposes of saving fresh water are costly and would suffocate rapid economic growth throughout the entirety of China. In addition, because the provision of electrical supplies over long distances requires enormous investments for the construction of power lines and transmission plants, electricity plants must be built in the northern portion of China, despite the fact that this region faces serious water resource shortage problems. However, it is relatively unimportant for the paper manufacturing industry to be located in the northern Chinese provinces. Thus, the migration of paper manufacturing companies from the Northern provinces to the southern provinces of China is one viable method of addressing the water resource shortages in the northern part of China.

As shown in Table 4, the inefficiency scores of thewaste water model tend to improve every year for the examined industries, except for the oil refining and power industries. The chemical and steel industries have reduced their wastewater discharge by more than 80% between 1996 and 2006. There are two main reasons that this improvement was achieved. One of these reasons is a decrease in industrial water use per unit of product. This decrease was caused by technological advancements in production processes and equipment. The other reason for the marked improvement in wastewater discharge for these industries is the improved capacity of wastewater treatment equipment. The Chinese government has established a goal for recycled water use ratios in its recent five-year plan, creating incentives for industries to raise their recycled water use ratios. In the 2000s, there has been a more active environmental market in China, a development that has caused the price of environmentally friendly equipment to decrease and encouraged technological innovation though market mechanisms.

Table 4. The productive inefficiency scores with respect to waste water discharge and the shadow prices of wastewater for the examined industries

	Inefficiency score						Shadow price of waste water (yuan/m^3)					
	Spinning	Paper	Oil	Chemical	Steel	Power	Spinning	Paper	Oil	Chemical	Steel	Power
1996	0.23	0.66	0.51	0.80	0.89	0.38	57.4	8.9	24.7	17.8	33.3	52.6
1997	0.13	0.65	0.58	0.76	0.89	0.50	64.7	8.8	216.4	21.4	34.9	42.7
1998	0.26	0.71	0.61	0.75	0.88	0.22	55.5	6.1	200.8	22.3	35.4	66.5
1999	0.22	0.63	0.61	0.68	0.85	0.27	58.2	8.4	199.5	29.2	47.0	61.9
2000	0.20	0.60	0.60	0.57	0.81	0.07	59.7	8.4	206.1	38.9	57.3	100.5
2001	0.18	0.52	0.49	0.53	0.75	0.27	61.2	10.4	258.4	42.6	76.1	78.6
2002	0.18	0.44	0.46	0.51	0.66	0.00	61.0	11.8	274.8	44.5	103.1	-
2003	0.08	0.31	0.45	0.31	0.72	0.15	68.5	14.5	278.8	62.4	85.2	85.9
2004	-	-	-	-	-	-	-	-	-	-	-	-
2005	0.05	0.17	0.00	0.00	0.00	0.35	71.0	17.4	-	-	-	55.3
2006	0.00	0.00	0.55	0.00	0.00	0.00	-	-	232.0	-	-	-

Conclusion

This study analyzes the inefficiencies and shadow prices of fresh water consumption and wastewater discharge in China by province and business type. An empirical analysis of the study results produces the following conclusions. First, most of the provinces that were evaluated as being efficient in reducing fresh water use and wastewater discharge are located in the northern regions of China. Four provinces, namely, Hebei, Shanxi, Ningxia and Guizhou, have higher inefficiency scores in the *efficiency improvement model* than in the *substitution* *model*. These results imply that in the Hebei, Shanxi, Ningxia and Guizhou provinces, the policies that produce incentives for the industrial sector to achieve water use efficiency improvement are more effective than the policies that restrict waste water discharge. Second, industrial water use efficiency tended to improve each year for all of the examined industries except for the oil refining industry. In addition, the shadow prices of the spinning and oil refining industries were relatively high, whereas the shadow prices of the paper and electricity industries were relatively low. Furthermore, the shadow prices and inefficiencies were different among distinct provinces and business types. The policy implication from this study is that the Chinese government must establish appropriate environmental and water price policies that account for these differences among theprovinces and industries of China to achieve sustainable development.

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Appendix

Fig. 1. The provinces of China