Water Efficiency of Industrial Sector in China

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Problem of water scarcity has been increasingly severe in China. Though industrial sectors play important role for the rapid economic growth, and they consumes water and discharge wastewater. The purpose of this study is to examine the efficiency of water use and wastewater discharge in comparison with those of other inputs and production output in Chinese industry. Measuring efficiency of each input and output factor from 2002 to 2008, we find the average inefficiencies of industrial water use and industrial waste water discharge are higher than those of capital, labor, and production output in China. In addition, the productivity levels to save water in the water shortage areas are not higher compared to the others. The water use inefficiency has a high dispersion especially in the regions where the amounts of water resources per capita is less than 3000 cubic meter.

Key Words : *Water Efficiency, Industrial Sector, China*

1. Introduction

Problem of water scarcity has been increasingly severe in China. Local water resources are insufficient to meet rising water consumption especially in northern part of China. Furthermore, increasing pollution damages water quality. Overexploitation of water resources brought serious environmental consequences of ground subsidence, salinity intrusion, and ecosystem deterioration[1), 2), 3), 4), 5), 6), 7), 8)].

In China, mining and manufacturing industries play important role for the rapid economic growth[9)]. Compared to other emerging country of India, the percentage of added value in the industry sector and export ratio of total GDP in China are higher than those in India. In 2008, these are 48.6% and 36.5% in China, respectively[10)].

Industry sector consumes industrial water and discharge industrial wastewater. We are interested in analyzing whether they do in an efficient way. Understanding water efficiency of Chine's industry helps to solve water scarcity and wastewater management with economic development of China.

Previous studies analyze efficiency of the water use and wastewater discharge in China. Hu et al.[11)] examines water efficiency of regions in China using data envelopment analysis (DEA). The data includes labor employment and capital stock as well as water as an input. They find a U-shape relation between the water efficiency and per capita real income among areas.

Yang and Abbaspour[12)] provides a systematic framework for evaluating the potential wastewater reuse quantities under technological, physical, economic and institutional constraints, taking Beijing as a case study. The results of the linear programming model suggest that the wastewater reuse potential is sensitive to the prices for reclaimed wastewater as well as freshwater for different uses. On the one hand, higher the cost of wastewater treatment, lowers the optimal scale of wastewater reuse. On the other hand, lower freshwater prices relate to the reclaimed wastewater prices discourage the reuse of the latter.

However, little is known about the joint effect of water use and wasterwater discharge efficiency of industry sector in overall China. The purpose of this paper is to examine the efficiency of water use and wastewater discharge in comparison with those of capital, labor, and production output in Chinese industry. Especially, this paper investigates whether the industrial water is used efficiently in the water shortage area.

To estimate efficiency of each input and output factor in this study we use the Weighted Russell

Directional Distance Model (WRDDM) following Fukuyama and Weber[13]. The directional distance function of this model seeks the maximum non-radial expansion in outputs and contraction in inputs for a given directional scaling vector, accounting for all slack in the input and output constraints.

As a characteristics of this directional distance measure, it does not incorporate input and output slacks when they are estimated using DEA[14]. Unlike the directional distance measures, radial measures of efficiency overestimate technical efficiency when there are nonzero slacks in the constraints defining the piece-wise linear technology. Thus, WRDDM suits for many applications in reality. This study uses data from China Statistical Yearbook conducted over the seven-year from 2003 to 2009[10].

2. Model

Let inputs be denoted by $x \in R_+^N$, good outputs by $y \in R_+^M$, and bad or undesirable outputs by $b \in R_+^J$. The directional distance function seeking to increase the desirable outputs and decrease the undesirable outputs and inputs directionally can be defined by the following formulation:

$$\vec{D}(x, y, b; g) = \sup\{\beta : (x - \beta g_x, y + \beta g_y, b - \beta g_b) \in T\}. \tag{1}$$

where the nonzero vector $g = (-g_x, g_y, -g_b)$ determines the directions in which inputs, desirable outputs and undesirable outputs are scaled. The technology reference set $T = \{(x, y, b) : x$ can produce $(-y, b)\}$ satisfies strong disposability of desirable outputs and inputs, and weak disposability of undesirable outputs.

Suppose there are $k = 1, \ldots, K$ decision making units (DMUs) in the data set. each DMU uses input $x^k = (x_1^k, x_2^k, \ldots, x_N^k) \in R_+^N$ to jointly produce desirable outputs $y^k = (y_1^k, y_2^k, \ldots, y_M^k) \in R_+^M$ and undesirable outputs $b^k = (b_1^k, b_2^k, \ldots, b_J^k) \in R_+^J$. By setting $g = (-g_x, g_y, -g_b) = (-x^k, y^k, -b^k)$, the WRDDM assuming variable returns to scale is shown as follows:

$$\begin{aligned}
&\vec{D}^R(x^k, y^k, b^k; g) \\
&= \beta^R = \max \frac{1}{N}\sum_{n=1}^{N}\beta_n^k + \frac{1}{M}\sum_{m=1}^{M}\beta_m^k + \frac{1}{J}\sum_{j=1}^{J}\beta_j^k \\
&s.t. \sum_{k=1}^{K} z_k y_{mk} \geq y_{mk} + \beta_m^k g_{ym},\ m = 1, \ldots, M, \\
&\sum_{k=1}^{K} z_k b_{jk} = b_{jk} - \beta_j^k g_{bj},\ j = 1, \ldots, J, \\
&\sum_{k=1}^{K} z_k x_{nk} \leq x_{nk} - \beta_n^k g_{xn},\ n = 1, \ldots, N, \\
&\sum_{k=1}^{K} z_k = 1, \\
&z_k \geq 0,\ k = 1, \ldots, K
\end{aligned} \tag{2}$$

where $\beta_m^k, \beta_j^k, \beta_n^k$ are the individual inefficiency measure for each desirable output, each undesirable output and each input. z_k are the intensity variables to shrink or expand the individual observed activities of DMU k for the purpose of constructing convex combinations of the observed inputs and outputs.

3. Data

This study uses data from China Statistical Yearbook[10] conducted over seven-year period from 2003 to 2009. We use the province-level data of National Bureau of Statistics of China.

Our measure of outputs is gross output value of industry as the desirable output and total volume of waste water discharge as the undesirable output. As inputs, we use three variables of net value of fixed assets of industry, number of employed persons, and water use in the industry. Table 1 shows the mean of the province during the sample period. There are three characteristics about the water issues in China (see Table 2 and Table 3).

First, the gross output value/m^3 of water use of industry increase greatly over seven years in China. Table 2 also shows the simple ratio output productivities of industry in developed country. In China the productivities are 11.72 U.S\$/m^3 in 2002 and 52.27 U.S\$/m^3 in 2008, catching up with the level in developed country.

The productivity improvement is not due to decreasing water use, but to increasing production. The gross output value of industry increases by an average of 28.9% per year over seven years. In contrast, the growth rate of the industrial water use and the industrial waste water volume are lower than that of the output value, and are 3.41% and 2.60% per year over the period, respectively.

Table 1 Sample average over 2002-2008.

Province	Capital: 100 mio yuan	Labor: 10,000 persons	Water use:100 mio m³	Gross Output: 100 mio yuan	Wastewater: 100 mio m³
North					
Beijing	2548.9	248.9	6.7	6753	1.2
Tianjin	2236.7	175.5	4.5	7242.6	2.3
Hebei	4186.5	1041.4	25.8	11822.1	12
Shanxi	3152.6	385.7	14.1	5201.2	3.6
Inner Mongolia	2273.4	166.6	13.9	3738.8	2.5
Northeast					
Liaoning	5279.5	495.9	22.6	12481.5	9.3
Jilin	2031.1	204.6	18.9	4561.1	3.7
Heilongjiang	2570.5	339.8	56.5	4835.7	4.4
East					
Shanghai	5228.7	330.8	78	16225	5.3
Jiangsu	9399.1	1514	192.4	35945.6	26.9
Zhejiang	6512.2	1356.2	58.6	24117.7	18.5
Anhui	2240.7	776.6	71.2	5430.9	6.7
Fujian	2688	591.4	64.1	8757.3	11.8
Jiangxi	1483.9	463.5	52.2	3809.9	5.8
Shandong	8934.9	1489.9	27.1	32984.2	14
South Central					
Henan	4197.9	1276.5	45.3	12602.2	12.4
Hubei	4068.1	547	86.2	7127.4	9.4
Hunan	2178.2	639	75.9	5632	11.1
Guangdong	9433	1446.6	133.7	38255.3	19.8
Guangxi	1433.4	383	44.5	3030.3	14.3
Hainan	345.6	39.7	3.9	607.6	0.7
Southwest					
Chongqing	1199	381.1	34.5	2977.5	7.9
Sichuan	3272.2	865.8	57	7282.9	11.7
Guizhou	1112.8	230.1	28.2	1797.2	1.5
Yunnan	1517.5	254.6	19.6	2964	3.5
Tibet	65.6	13.3	0.7	32.4	0.1
Northwest					
Shaanxi	2252.3	349.7	12.6	3878.3	4
Gansu	1254.2	185.9	15.4	2172.4	1.8
Qinghai	597.5	47.4	5.9	555.6	0.6
Ningxia	473	66.2	3.5	727.1	1.6
Xinjiang	1515.9	102.6	8.9	2302.7	1.9
Overall	95682.9	16409.3	1282.4	275851.5	230.3

Table 2 Industrial water use and gross industrial output value in China and developed countries.

Country	Year	Industrial water use: 100 mio m³	Gross Industrial Output Value (100 mio U.S.$)	Efficiency (U.S. $/ m³)	Source
China	2002	1142.4	13383.7	11.72	(a)
	2003	1177.2	17188.7	14.60	(a)
	2004	1228.8	23810.5	19.38	(a)
	2005	1285.2	30707.8	23.89	(a)
	2006	1343.8	39707.6	29.55	(a)
	2007	1403.0	53256.7	37.96	(a)
	2008	1397.1	73024.6	52.27	(a)
U.S.	2000	3028.6	69383.0	22.91	(b)
	2005	3083.5	57836.0	18.76	(b)
Japan	2000	134.0	36533.2	272.64	(c)
	2005	133.0	37524.5	282.14	(c)
France	2000	219.7	8669.9	39.46	(d)
	2005	232.6	10589.9	45.53	(d)
Italy	2000	162.9	10761.5	66.06	(e)
Germany	2000	319.3	17120.8	53.62	(e)
U.K.	2000	71.9	4092.4	56.92	(e)
Canada	2000	315.7	5785.9	18.33	(e)

Notes: (1) Data sources of industrial water use are as follows: (a) China Statistical Yearbook 2003-2009[10]; (b) Estimated Use of Water in the United States in 2005[15]; (c) Census of Manufactures in Japan[16]; (d) Eurostat[17]; (e) Aquastat[18].
(2) Data of gross industrial output value is from UNdata[19].

Table 3 Correlation of variables.

	Net value of fixed assets of industry	Labor of industry	Water use of industry	Gross output value of industry	Waste Water discharge of industry	Total amount of water resources	Total water use	Electricity production
Net value of fixed assets of industry	1.00							
Labor of industry	0.84	1.00						
Water use of industry	0.63	0.67	1.00					
Gross output value of industry	0.97	0.83	0.62	1.00				
Total volume of wastewater discharge	0.74	0.88	0.79	0.73	1.00			
Total amount of water resources	−0.14	−0.02	0.08	−0.08	0.07	1.00		
Total water use	0.49	0.56	0.71	0.48	0.67	0.15	1.00	
Electricity production	0.89	0.85	0.60	0.84	0.73	−0.10	0.51	1.00

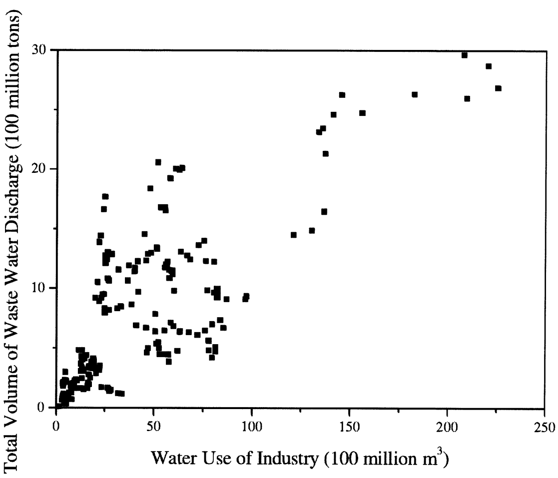

Fig. 1 Water use and wastewater discharge of Chinese industry over 2002-2008.

Table4 Average efficiency over 2002-2008.

			All	Input	Capital	Labor	Water use	Output Production	Wastewater
Region	Province	coastal	β	β	β	β	β	β	β
North	Beijing		0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Tianjin	✓	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Hebei	✓	0.385	0.460	0.140	0.584	0.657	0.057	0.638
	Shanxi		0.478	0.391	0.193	0.407	0.572	0.454	0.588
	Inner Mongolia		0.481	0.302	0.118	0.095	0.693	0.698	0.442
Northeast	Liaoning	✓	0.286	0.331	0.323	0.131	0.537	0.000	0.526
	Jilin		0.410	0.315	0.012	0.176	0.756	0.381	0.535
	Heilongjiang		0.511	0.360	0.000	0.306	0.774	0.656	0.518
East	Shanghai	✓	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Jiangsu	✓	0.111	0.128	0.021	0.046	0.318	0.000	0.205
	Zhejiang	✓	0.151	0.192	0.012	0.149	0.415	0.000	0.262
	Anhui		0.538	0.500	0.000	0.694	0.808	0.474	0.640
	Fujian	✓	0.412	0.478	0.000	0.578	0.855	0.023	0.736
	Jiangxi		0.567	0.475	0.000	0.620	0.806	0.566	0.660
	Shandong	✓	0.000	0.000	0.000	0.000	0.000	0.000	0.000
South Central	Henan		0.408	0.440	0.022	0.560	0.738	0.191	0.592
	Hubei		0.577	0.299	0.000	0.165	0.734	0.966	0.467
	Hunan		0.576	0.450	0.000	0.580	0.770	0.551	0.727
	Guangdong	✓	0.000	0.000	0.000	0.000	0.000	0.162	0.117
	Guangxi	✓	0.696	0.408	0.000	0.516	0.708	0.676	0.725
	Hainan	✓	0.439	0.274	0.009	0.140	0.673	0.505	0.538
Southwest	Chongqing		0.576	0.435	0.000	0.606	0.700	0.499	0.793
	Sichuan		0.586	0.373	0.000	0.493	0.625	0.779	0.604
	Guizhou		0.577	0.460	0.000	0.498	0.882	0.737	0.534
	Yunnan		0.551	0.405	0.000	0.422	0.795	0.601	0.645
	Tibet		0.000	0.000	0.000	0.000	0.000	0.000	0.000
Northwest	Shaanxi		0.577	0.311	0.000	0.372	0.560	0.894	0.527
	Gansu		0.534	0.371	0.000	0.337	0.776	0.744	0.487
	Qinghai		0.692	0.275	0.179	0.000	0.645	1.696	0.107
	Ningxia		0.638	0.271	0.000	0.272	0.542	0.930	0.714
	Xinjiang		0.474	0.283	0.174	0.000	0.675	0.750	0.389
North			0.331	0.342	0.105	0.386	0.536	0.147	0.504
Northeast			0.373	0.362	0.174	0.196	0.716	0.234	0.525
East			0.189	0.225	0.007	0.221	0.446	0.036	0.306
South Central			0.355	0.271	0.005	0.321	0.488	0.310	0.485
Southwest			0.581	0.407	0.000	0.505	0.716	0.673	0.664
Northwest			0.570	0.335	0.061	0.280	0.663	0.873	0.501
Overall			0.303	0.293	0.043	0.304	0.531	0.172	0.443

Second, there is little relationship between the amounts of water use and water resources in China. Table 3 presents a correlation matrix of our data. The correlation coefficient between total amount of water resources and total water use is 0.147. The amounts of water resources differ widely in each province. The surface water percentages of each total water supply also vary in each province. Generally, these percentages are higher in South China, and lower in North and Northeast China.

Third, the amount of industrial water use correlates with the volume of waste water discharge. The correlation coefficient between these variables is 0.790. Fig. 1 shows that the volumes of waste water discharge per industry water use varies in each province in each year.

4. Result

Table 4 reports the results of the production measures. Each β denotes inefficiencies of each input, desirable output, or undesirable output factors. These numerical values indicate average potential rates of inputs and undesirable output reduction, and the rates of desirable output increase from 2002 to 2008. The potential rates in six regions and whole of country are weighted average value of each province's efficiency.

As the overall results, the average inefficiencies of industrial water use and industrial wastewater discharge are higher than those of capital, labor, and production output in China. Regarding the results of input factors, the average inefficiencies of capital, labor, and water use are 0.043 (413.4 billion yuan), 0.304 (49.9 million persons), and 0.531 (68.1 billion m^3), respectively. Those of output production and wastewater discharge are 0.172 (4,749 billion yuan) and 0.443 (10.2 billion m^3), respectively.

Table 5 shows mean changes of the inefficiency values over time. The average inefficiency change of

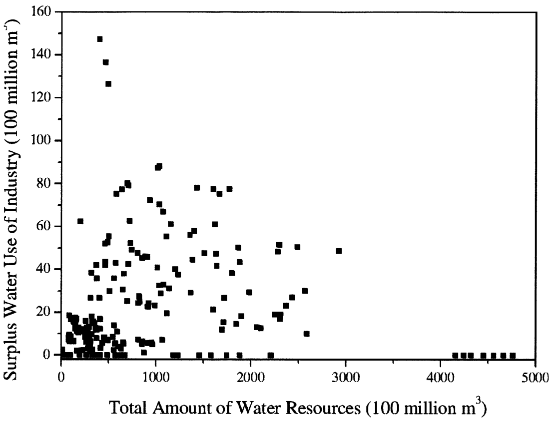

Fig. 2 Surplus industrial water use toward total water resource over 2002-2008.

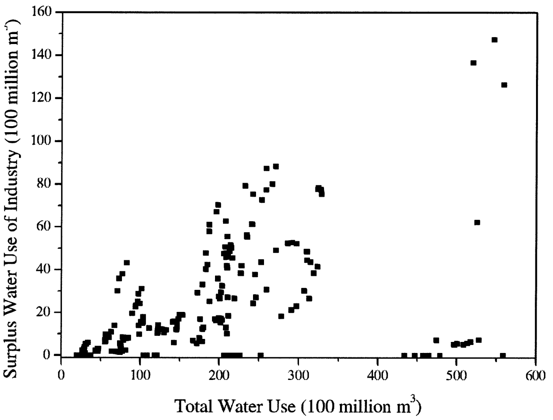

Fig. 3 Surplus industrial water use toward total water use over 2002-2008.

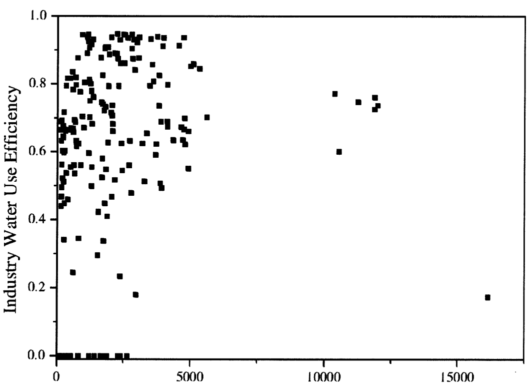

Fig. 4 Water use inefficiency of industry toward total water resources per capita.

Notes: (1) Tibet is excluded from Fig. 4. In Tibet, total water resource per capita is quite large, and the industrial water is used in the most efficient way.

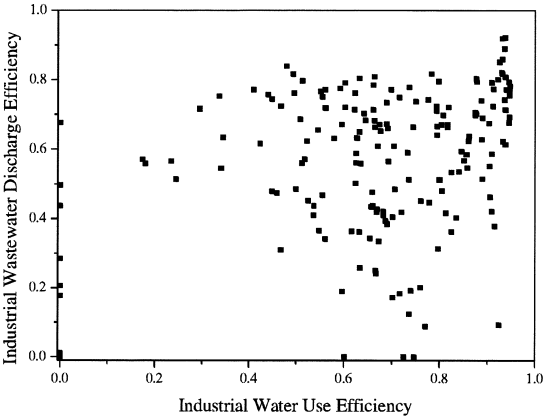

Fig. 5 Integrated index of both industrial water use and wastewater discharge.

Table 5 Average efficiency over 2002-2008.

	All	Input	Capital	Labor	Water use	Output	Waste water
Region	β	β	β	β	β	β	β
North	−0.005	0.007	0.018	−0.014	0.015	−0.019	−0.002
Northeast	−0.012	−0.008	−0.017	−0.014	0.009	−0.018	−0.011
East	0.015	0.019	0.002	0.019	0.036	−0.002	0.027
South Central	0.001	0.013	0.003	0.003	0.032	−0.008	−0.002
Southwest	−0.008	0.031	0.000	0.023	0.072	−0.055	−0.001
Northwest	0.002	−0.011	−0.001	−0.028	−0.005	0.000	0.017
Overall	0.004	0.013	0.001	0.007	0.033	−0.010	0.009

water use is higher than those of the other input and output in Chinese industry. Its value is 0.033, and means the amount of surplus water use increases 9.7 billion m^3 on average from 2002 to 2008. In contrast, the average inefficiency change of output production is −0.010, and is only negative number among inputs and outputs.

Regarding the input factor efficiencies, the average changes of the inefficiencies in capital, labor, and water use are 0.001, 0.007, and 0.033, respectively. Most efficient regions from the viewpoint of industrial water and discharging industrial wastewater are Beijing, Tianjin, Shanghai, Shandong, Guangdong, and Tibet. These regions have 2 features. First, except for Guangdong, they are also the most efficient regions in perspective of capital and labor, and output. Second, these regions except for Tibet are coastal provinces or a near coastal city, and have relatively large amounts of production (we note data of Tibet might be less reliable than others).

Fig. 2 and Fig. 3 show the potential reduction in industrial water use toward total water resource and total water use. The potential reduction in industrial water use would be large in the regions with less water resources. The surplus industrial water use correlates not with that of water resources, but with the amount of water use. These correlation coefficient are 0.112 and 0.581, respectively.

In addition, the technology levels to save water in the water shortage areas would not be relatively high among all provinces. The correlation coefficient between the water use inefficiency and the amount of water resource per capita is −0.281. However, the water use inefficiency has a high dispersion especially in the regions where the amounts of water resources per capita are less than 3,000 m^3 (Fig. 4). The industrial water use efficiency seems not to be related to some water shortage indices such as total water resources per capita.

Fig. 5 presents an integrated index of both industrial water use and wastewater discharge efficiencies pooled from 2002 to 2008. This indicates there are many inefficient provinces in both using water and discharging wastewater. It does not mean that there seems a exact linear relationship between both inefficiencies, but the both inefficiencies are more than 0.5 in the 47.47% of all provinces.

5. Conclusion

In this study we measure the inefficiency of industry in China from 2002 to 2008 taking account not only capital, labor, and production output, but also water use and wastewater discharge jointly. Our empirical analysis shows the following two results.

First, the average inefficiencies of industrial water use and industrial wastewater discharge are higher than those of capital, labor, and production output in China. It does not imply that there seems a exact linear relationship between both inefficiencies, but there are many inefficient provinces in both using water and discharging wastewater.

In addition, the average inefficiency change of water use is higher than those of the other input and output factors in Chinese industry. The amount of surplus water use would increases 9.74 billion m^3 on average.

Second, the productivity levels to save water in the water shortage areas are not high compared to the others. The water use inefficiency has a high dispersion especially in the regions where the amounts of water resources per capita is less than 3,000m^3. In other words, the potential reduction in industrial water use would be large in the regions with less water resources.

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