Wastewater Management Efficiency and Determinant Factors in the Chinese Industrial Sector from 2004 to 2014

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Abstract: This study analyzes industrial wastewater management efficiency using a Chinese provincial dataset from 2004 to 2014. The weighted Russell directional distance model is used to evaluate the efficiency of management practices. Determinants analysis was conducted based on governmental policy, pollution abatement, and market factors to identify the main drivers of industrial wastewater management efficiency in China. The results indicate that the wastewater management efficiency improved in the eastern and central regions. However, there is a significant efficiency gap between provinces in the western region. Moreover, the main determinants of wastewater management efficiency differ among regions and pollutants.

1. Introduction

1.1. Water Problems in China

China has achieved dramatic economic development through industrialization. However, many environmental problems have occurred as a result of increases in industrial pollution [1]. These environmental problems are serious, and water pollution is a particularly major issue in northern China, which is experiencing a water resource shortage [2]. In addition, according to Cai et al. [3], water resources in the coastal area appear to be more vulnerable than those in other regions in China. Additionally, water pollution has been steadily worsening in most parts of the country, even though the water use efficiency has substantially increased.

Health problems caused by polluted water are another important issue in China. Guardian [4] reported that four-fifths of the country's underground water drawn from wells is unsafe for drinking because of pollution. According to Wang and Yang [5], the negative effects of water pollution on human health remain a major source of morbidity and mortality. Lu et al. [6] reported that water pollution by chemical substances is one of the most important factors that influences food safety and human health in China. Additionally, Tao and Xin [7] reported that every year, 190 million people fall ill and 60,000 people die from diseases caused by polluted water in China.

To solve these water pollution problems, the Chinese government has promulgated environmental policies to promote wastewater management in urban and rural areas [8,9]. According to Shao [10], the Chinese government has enacted more than 130 policies related to environmental protection since 1979 to halt the deterioration of aquatic environments and improve the quality of surface water.

*1.2. Industrial Wastewater Management Policies and Trends in China*

Table S1 presents a summary of the environmental policies and projects related to wastewater management in China. Table S1 shows that chemical oxygen demand (COD) and ammonia nitrogen (NH$_3$-N) are key pollutants that are the focus of wastewater pollution management in the 11th and 12th Five-Year Plans. According to Jia et al. [11], COD and NH$_3$-N are often considered the best indicators for evaluating the degree of water pollution because of their advanced measurement methods. COD reflects the organic carbon content, and NH$_3$-N indicates the nitrogen content of wastewater.

Because of these environmental regulations and policies, COD and NH$_3$-N emissions have been reduced in China. Figure 1 shows the trends in industrial wastewater pollutants from 2004 to 2014. As shown in Figure 1, COD and NH$_3$-N emissions decreased rapidly during this period, even though industrial water use and the wastewater discharge volume did not change substantially. This finding implies that China's wastewater pollutant management policies were successful during this period because of their effective pro-environmental strategies and the associated projects.
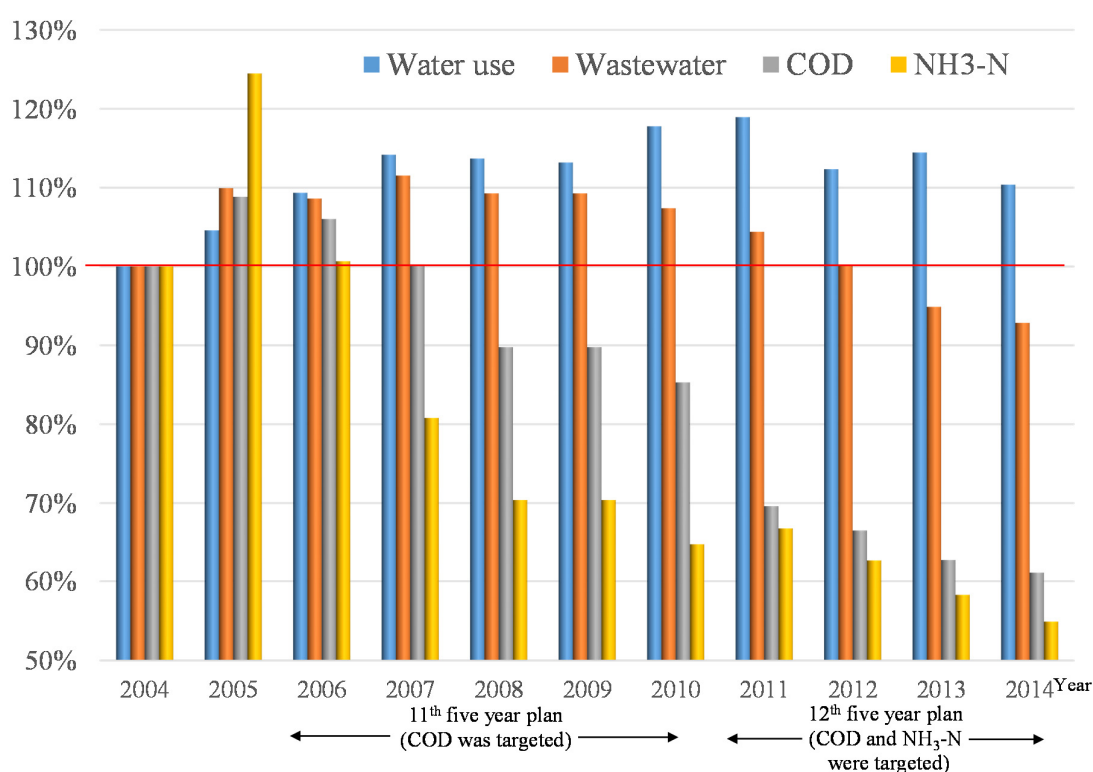
Figure 1. Changes in industrial water use, wastewater, and pollutant discharge in China. Note: The vertical axis indicates the change in each variable (year 2004 = 100%). Source: China Statistical Yearbook on the Environment [12].

However, wastewater pollutant emission reductions vary between the regions of China. Figure 2 shows the change in the regional distribution of the wastewater pollution intensity from 2004 to 2014. As shown in Figure 2, the pollution intensity decreased rapidly in the east coast and central areas, while the western region did not substantially improve in comparison to the other regions.
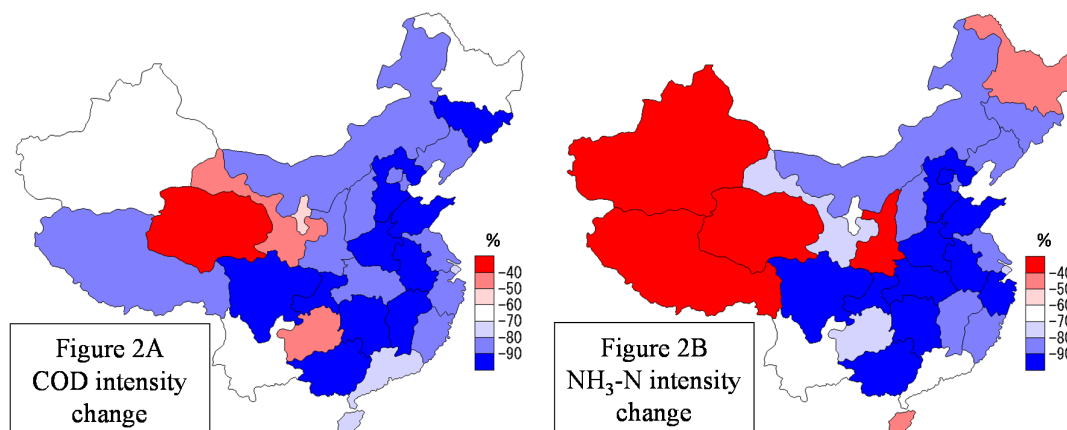
Figure 2. Regional distribution of changes in the intensity of wastewater pollution from 2004 to 2014. Note: The chemical oxygen demand (COD) ammonia nitrogen (NH_3-N) intensity is defined as the ratio of industrial COD (NH_3-N) emissions to industry revenue. Source: China Statistical Yearbook on the Environment [12].

One interpretation of this result is that the eastern coastal area of China has the most developed economy, which led to substantial water pollution emissions in 2004 [13]. Thus, the coastal area had the potential for substantial pollution reductions. Additionally, Han et al. [14] reported that the river water in the eastern regions was highly polluted, which provided an incentive for local governments to better manage their wastewater. In contrast, a low pollution intensity was observed in the western provinces in 2004, and they therefore had less potential for additional emission reductions [15].

1.3. Objective and Research Framework

These regional disparities in water pollution management represent key information for proposing effective policies to achieve both economic development and environmental protection in China considering the regional characteristics. Additionally, regional environmental policy plays an important role in achieving economic development and wastewater pollution control through infrastructure construction and appropriate pollution abatement in industrial sectors [8,16].

According to Fujii et al. [17], Chinese industrial sectors successfully improved their wastewater quality after 1998. The authors noted that the main driver of wastewater pollutant reduction varied by pollutant. However, their study did not identify the determinants of effective wastewater pollution management. Clarifying the determining factors in pollution abatement performance is useful, and the results can be used to develop environmental policies to control specific wastewater pollutant substances.

Based on this background, the present study analyzes the determining factors in wastewater pollutant abatement performance using both production efficiency as a performance evaluation method and an econometric approach for the analysis of determinants. The objective of this study is to clarify the determining factors that affect wastewater pollution management performance in Chinese industrial sectors.

Figure 3 shows the research framework of this study. The methodological approach of this paper involves two steps. First, we estimate the wastewater management efficiency by taking measures of undesirable output variables (i.e., pollution) into account. Second, we attempt to explain the regional differences in efficiency scores based on (1) pollution reduction targets; (2) pollution abatement factors; and (3) market factors.
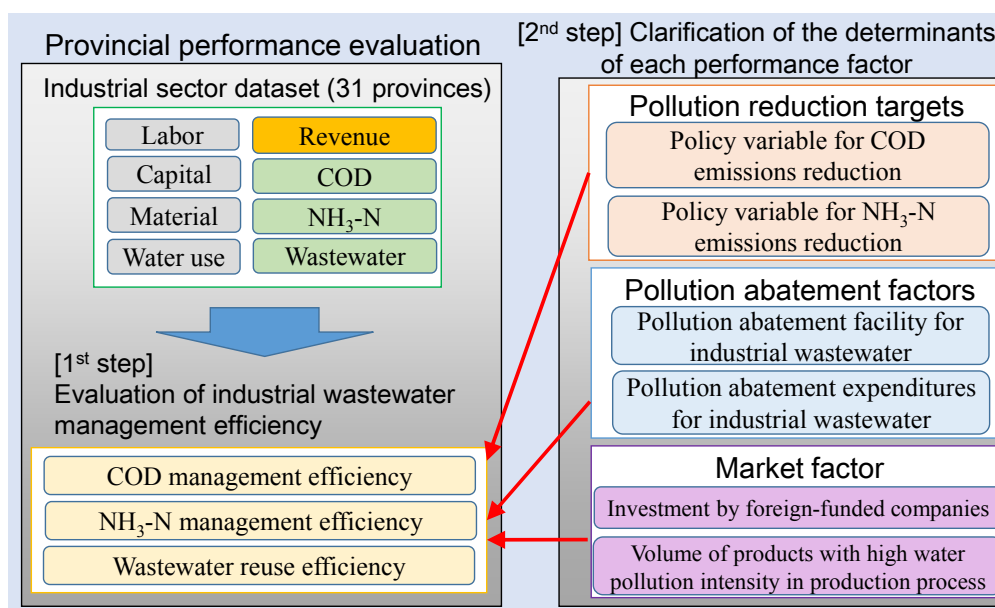
Figure 3. Research framework of this study.

2. Methodology

This study measures the wastewater management efficiency in Chinese industrial sectors. We applied the weighted Russell directional distance model (WRDDM) to measure wastewater management efficiency using the production technology theory, following Barros et al. [18] and Chen et al. [19]. They proposed a measure based on a directional distance function that is evaluated in linear form and, hence, has the advantages of easy computation and easy extension by incorporating additional undesirable outputs (i.e., pollutants) into the programming measure. The WRDDM has been widely applied in the resource and environmental management research fields [20].

2.1. Weighted Russell Directional Distance Model (WRDDM)

Let inputs be denoted by $x \in R_+^N$, good outputs by $y \in R_+^M$, and bad or undesirable outputs by $b \in R_+^L$. The inefficiency score $\overrightarrow{D}(x, y, b|g)$ is defined based on the distance β from the production frontier curve, consisting of the efficient provinces, as follows:

$$\overrightarrow{D}(x, y, b|g) = \sup\left\{ \beta : \left(x + \beta g_x, \ y + \beta g_y, \ b + \beta g_b \right) \in T \right\} \tag{1}$$

where the vector $g = \left(g_x, \ g_y, \ g_b \right)$ determines the directions in which the inputs, desirable outputs, and undesirable outputs flow. The vector specifies the best way for inefficient provinces to move their wastewater management efficiency toward the frontier production line. The technology reference set $T = \{(x, y, b): x \text{ can produce } (y, b)\}$ satisfies the strong disposability of desirable outputs and inputs and weak disposability of undesirable outputs.

This study used a Chinese provincial dataset, and the provincial names were set as $j = 1, 2, \cdots, k, \cdots, 31$. Each province used inputs $x = (x_1, x_2, \cdots, x_N) \in R_+^N$ to jointly produce desirable outputs $y = (y_1, y_2, \cdots, y_M) \in R_+^M$ and undesirable outputs $b = (b_1, b_2, \cdots, b_L) \in R_+^L$. Following Barros et al. [18] and Chen et al. [19], the WRDDM inefficiency calculation with variable returns to scale for province k can be described as follows:

$$\overrightarrow{D}(x, y, b|g) = maximize\left(\frac{1}{N} \sum_{n=1}^{N} \beta_n^k + \frac{1}{M} \sum_{m=1}^{M} \beta_m^k + \frac{1}{L} \sum_{l=1}^{L} \beta_l^k \right) \tag{2}$$

subject to

$$\sum_{j=1}^{31} z_j y_{mj} \geq y_{mk} + \beta_m^k g_{ymk} \tag{3}$$

$$\sum_{j=1}^{31} z_j b_{lj} = b_{lk} + \beta_l^k g_{blk} \tag{4}$$

$$\sum_{j=1}^{31} z_j x_{nj} \leq x_{nk} + \beta_n^k g_{xnk} \tag{5}$$

$$\sum_{j=1}^{31} z_j = 1 \tag{6}$$

$$Z_j \geq 0, \ j = 1, 2, \cdots, k, \cdots, 31 \tag{7}$$

where β_m^k, β_l^k, and β_n^k are the individual inefficiency measures of desirable outputs, undesirable outputs, and inputs, respectively. Z_k is the intensity variable used to shrink or expand the individual observed activities in province k for the purpose of constructing convex combinations of observed inputs and outputs.

To estimate the wastewater management efficiency score, we established a proportional, undesirable output-oriented directional vector $= \left(g_{xnk}, g_{ymk}, g_{blk} \right) = (0, 0, -b_{lk})$. This type of directional vector assumes that an inefficient province can improve its wastewater management efficiency by decreasing undesirable outputs. One advantage of the proportional, undesirable output-oriented vector is that the inefficiency score β can be defined from zero to one.

Additionally, inefficiency measures can be easily converted into efficiency scores using the score of "$1 - \beta$". Thus, in this study, we define the wastewater management efficiency using the score of "$1 - \beta$"; hence, the efficiency score is also defined from zero to one, where higher scores represent greater efficiency.

2.2. Determinant Analysis Using a Panel Tobit Regression Model

The wastewater management efficiency scores that are estimated by the WRDDM use pooled data (deemed the pooled WRDDM). The results of the pooled WRDDM were used as dependent variables in a panel Tobit model to identify the determining factors that contribute to improving the wastewater management efficiency (see Figure 3).

The panel Tobit model represents a situation in which the dependent variables are censored and limited. This condition is important in the context of this study because wastewater management efficiency estimated in the pooled WRDDM ranges from zero to one. We believe that the Tobit regression model is appropriate for determining the sources of efficiency. By defining Z as independent variables (i.e., determinant variables of efficiency), ε as an error term, *EFF* as the observed wastewater management efficiency score and *EFF** as a latent variable, the panel Tobit regression analysis can be described as follows.

$$EFF_j^* = \beta_0 + \beta Z_j + \varepsilon_j \tag{8}$$

$$EFF_j = EFF_j^* \ if \ 0 \leq EFF_j^* \leq 1 \tag{9}$$

$$EFF_j = 0, \ otherwise \tag{10}$$

3. Data and Model

The data for the study were collected from two main sources: the China Statistical Yearbook on the Environment [12] and the China Statistical Yearbook [21] published by the National Bureau of Statistics of the People's Republic of China. The dataset covers the 31 provinces and the eleven-year period from 2004 to 2014. To understand the differences in regional characteristics, we defined four regional

groups: the east coast, central, western, and northern areas. Details of the regional classification are provided in the Supplementary Material.

The main variables used in the analysis were revenue as a desirable output; labor wages, assets, cost of sales (Material), and industrial water use as inputs; and wastewater discharge, COD emissions and NH_3-N (ammonia) emissions as the undesirable outputs. COD and NH_3-N were selected as national targets for water pollution reduction in China. Additionally, these two variables are usually considered the best indicators for measuring the degree of water pollution, focusing on the organic carbon and nitrogen contents of industrial wastewater [11].

In the WRDDM calculations, we used a provincial-level panel dataset. The sample size was 341 observations (31 provinces × 11 years). All financial data variables were deflated to year 2010 prices. In this case, we can describe the pooled WRDDM calculation of province *k* as follows.

$$\vec{D}_k(x_k, y_k, b_k | g) = maximize \left(\tfrac{1}{3}\beta^k_{wastewater} + \tfrac{1}{3}\beta^k_{COD} + \tfrac{1}{3}\beta^k_{Ammonia} \right) \tag{11}$$

subject to

$$\sum_{j=1}^{341} z_j Revenue_j \geq Revenue_k \tag{12}$$

$$\sum_{j=1}^{341} z_j Wastewater_j = Wastewater_k \times \left(1 - \beta^k_{Wastewater} \right) \tag{13}$$

$$\sum_{j=1}^{341} z_j COD_j = COD_k \times \left(1 - \beta^k_{COD} \right) \tag{14}$$

$$\sum_{j=1}^{341} z_j Ammonia_j = Ammonia_k \times \left(1 - \beta^k_{Ammonia} \right) \tag{15}$$

$$\sum_{j=1}^{341} z_j Material_j \leq Material_k \tag{16}$$

$$\sum_{j=1}^{341} z_j Labor_j \leq Labor_k \tag{17}$$

$$\sum_{j=1}^{341} z_j Capital_j \leq Capital_k \tag{18}$$

$$\sum_{j=1}^{341} z_j Wateruse_j \leq Wateruse_k \tag{19}$$

$$z_j \geq 0, \ j = 1, 2, \cdots, k, \cdots, 341 \tag{20}$$

$\beta^k_{wastewater}$ reflects how inefficiently the industrial sector discharges wastewater compared with a frontier curve representing efficient provinces. For a given industrial water use (e.g., $Wateruse_k$), a reduction in wastewater discharge can be considered an improvement in wastewater reuse performance. Thus, we consider $\beta^k_{wastewater}$ as the proxy variable for wastewater reuse efficiency in this study.

Table 1 provides an overview of the data used in this study. As shown in Table 1, revenue, wages for labor, capital assets, and cost of sales increased from 2004 to 2014. By contrast, COD and NH_3-N rapidly decreased beginning in 2005, especially NH_3-N, which decreased by almost by half during this period. It should be noted that phosphorous is another major pollutants for wastewater quality measure. Meanwhile, China Statistical Yearbook on the Environment [12] only reports the phosphorous emissions in country level data which include agricultural and household sectors. Because of this data availability, this study only focus on the COD and NH_3-N emissions from industrial sector as wastewater pollutants substances.

Table 1. Descriptions of variables used in efficiency measurements.

	Input Variables				Desirable Output Variable	Undesirable Output Variables		
	Wages of labor	Capital assets	Cost of sales	Industrial water use	Revenue	Industrial wastewater	COD emissions	NH$_3$-N emissions
Year	(million yuan)	(million yuan)	(million yuan)	(10,000 tons)	(million yuan)	(10,000 tons)	(tons)	(tons)
2004	218	7540	5945	396,410	7133	71,336	164,419	13,607
2005	245	9026	7671	414,581	9108	78,423	178,946	16,938
2006	284	10,443	9441	433,471	11,203	77,482	174,326	13,697
2007	328	12,267	11,585	452,597	13,857	79,564	164,859	10,994
2008	360	13,974	13,710	450,674	16,199	77,952	147,608	9578
2009	437	17,004	15,734	448,684	18,663	77,952	147,608	9578
2010	486	19,125	18,879	466,877	22,508	76,604	140,247	8798
2011	608	20,543	21,530	471,484	25,589	74,476	114,452	9071
2012	682	23,762	24,264	445,323	28,730	71,479	109,179	8521
2013	984	26,882	27,667	453,710	32,441	67,690	103,054	7930
2014	1088	30,902	30,339	437,548	35,597	66,240	100,436	7471

Note: All monetary variables are deflated to year 2010 prices.

We applied five independent variables in the panel Tobit analysis. First, we used total investment from foreign-funded companies. Investment from foreign-funded companies in a developing country is expected to improve industrial production technology, including environmental protection, due to technology transfer [22].

The second and third independent variables were the capacity for industrial wastewater treatment and the abatement cost of industrial wastewater. These factors contribute to reducing pollution and improving the resource use efficiency [23]. The fourth variable was the change in the production scale of high water-polluting industries, such as textile and paper producers. Because the wastewater pollution intensity varies by industry, a change in the industrial composition will clearly affect the level of industrial wastewater pollutants [17]. Thus, we applied changes in the production scale of high pollution intensity products to control for changes in the industrial composition. We identified four products (chemical fibers, cloth, machine-made paper, and crude oil) as high pollution intensity products for industrial wastewater.

Finally, we applied two dummy variables that represent the environmental policies geared toward industrial wastewater management: a COD emission reduction target and an NH$_3$-N emission reduction target. These variables reflected the COD and NH$_3$-N reduction targets set by the Chinese government in the 11th and 12th Five-Year Plans as national goals.

Table 2 provides descriptions of the variables used in the determinant analysis. Additionally, we estimated the correlation scores and variance inflation factors (VIFs) of the independent variables to check for multicollinearity problems. Because the VIF scores of all control variables were below 4.0, we concluded that there were no multicollinearity problems in our estimation.

**Table 2.** Descriptions of variables used in the determinant analysis.

| Variables (Code)	Units	Mean Value	Std. Dev.	Min.	Max.
COD emissions reduction target (COD target)	Dummy variable	0.818	0.386	0.000	1.000
NH$_3$-N emissions reduction target (NH$_3$-N target)	Dummy variable	0.364	0.481	0.000	1.000
Total investment by foreign-funded companies (Foreign)	Billion US$	7.910	12.233	0.030	71.810
Production-scale change of high water pollution intensity products (Polluted)	Year 2004 = 1	2.311	4.259	0.364	36.342
Capacity of industrial wastewater treatment facilities (Capacity)	Million tons per day	7.441	7.323	0.008	63.912
Pollution abatement cost of wastewater treatment (Abatement)	Billion yuan	1.607	1.594	0.001	9.667

4. Results

4.1. Efficiency Scores for Industrial Wastewater Management

Figures 4 and 5 show the change in three wastewater management efficiencies from 2004 to 2014. As shown in Figure 4, all three wastewater management efficiencies largely improved in this period in the east and central regions, and in particular, the three efficiency scores in the coastal area were larger than those in the other regions in 2014. This result implies that the east and central provinces rapidly improved their wastewater management strategies from 2004 to 2014. One interpretation of this result is that both end-of-pipe treatment and cleaner production in industrial wastewater management have been widely induced in China in this period [17].
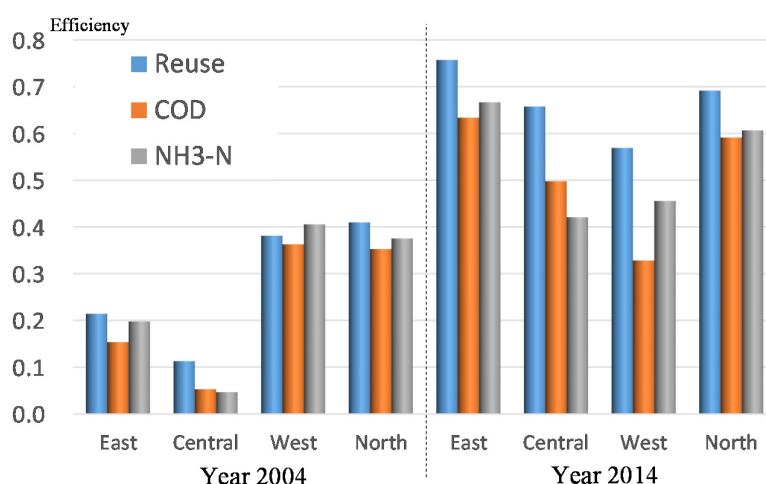
Figure 4. Regional average wastewater management efficiency from 2004 to 2014.
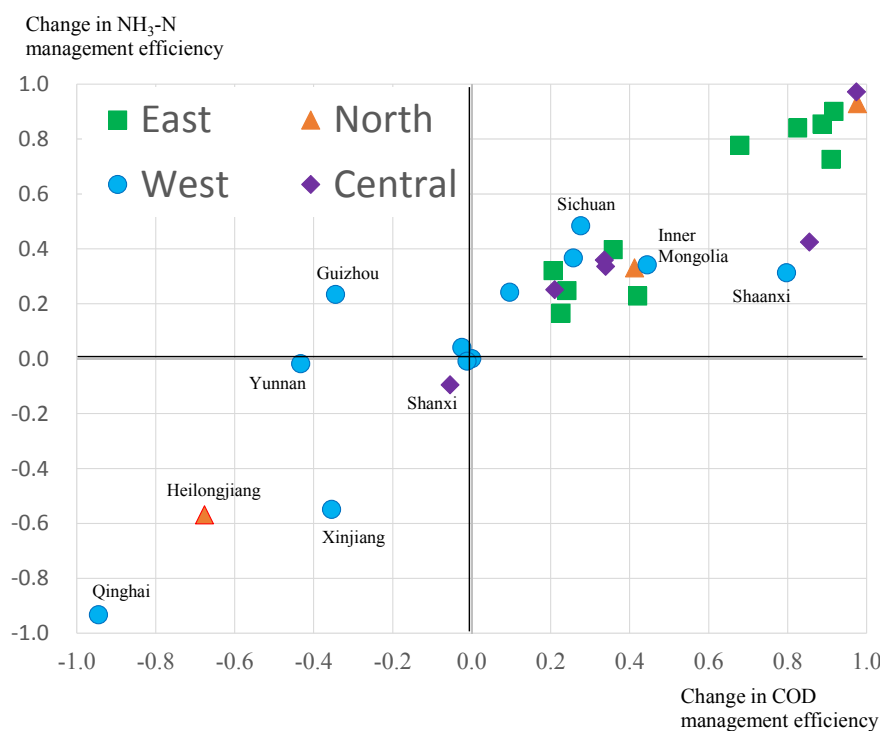
Figure 5. Changes in the COD and NH$_3$-N emission management efficiencies from 2004 to 2014 by region.

In addition to the eastern area, the northern region also improved its wastewater management efficiency, especially its wastewater reuse efficiency. However, the improvement in efficiency was relatively small in the western region compared with that in other regions. Surprisingly, the COD management efficiency in the western region worsened from 2004 to 2014, even as other regions achieved substantial improvements.

Next, we discuss the relationship between the change in COD management efficiency and the change in NH_3-N management efficiency by region. Figure 5 presents a scatter plot of the change in efficiencies of COD management and NH_3-N management by province from 2004 to 2014. Positive efficiency change scores represent efficiency improvements from 2004 to 2014. Thus, the upper right quadrant in Figure 5 represents improvements in both wastewater pollutant management efficiencies, while the lower left quadrant represents decreases in both efficiencies.

Figure 5 shows that many eastern and central provinces achieved combined improvements in the management of the two pollutants from 2004 to 2014. By contrast, many western provinces had scores in the lower left quadrant or close to the origin, which suggests that the wastewater management efficiencies of these provinces decreases or exhibited little change, even as the provinces in other regions improved their management of both pollutants. One interpretation of this regional disparity is that the wastewater pollution intensity increased due to the construction of new industrial plants in the western provinces as part of the Western China Development policy [20].

Figure 5 also indicates that Qinghai, Heilongjiang, and Xinjiang Provinces are the main areas where the wastewater management efficiency worsened from 2004 to 2014. In addition to these provinces, Yunnan and Guizhou Provinces also exhibited decreases in COD management efficiency. These provincial performances caused the overall COD management efficiency to decline in the western region from 2004 to 2014 (see Figure 4). Meanwhile, Sichuan, Inner Mongolia, and Shaanxi Provinces, which are also located in the western region, improved both efficiencies.

It is important to clarify the reasons for these different trends in changes in efficiency within the western region of China. Identifying the main determinants of the efficiency gaps is important for the development of environmental policies to improve industrial wastewater management performance. To investigate these determinants, we applied an econometric analysis as the second step in identifying the main influential factors.

4.2. Determinants of Industrial Wastewater Management Efficiency

Table 3 shows the results of the panel Tobit analysis using the three wastewater management efficiencies as dependent variables. In the panel Tobit analysis, we set the lower bound equal to zero and the upper bound equal to one for the dependent variables because the efficiency scores are defined from zero to one. The sample size was 341 (31 provinces × 11 years), and we set the cross-term variables using the western region as the dummy (West).

As shown in Table 3, the national reduction targets for COD emissions and NH_3-N emissions contributed to the increases in the COD management efficiency and NH_3-N management efficiency. Furthermore, total investment by foreign-funded companies significantly improved all three wastewater management efficiencies. This result is consistent with previous research [24]. However, we did not observe a significant effect of the production scale of high water pollution intensity products on efficiency. One interpretation of this result is that production-scale expansion and the progress in pollution abatement technology in China cancelled each other out. Zheng et al. [25] reported that the development of industrial wastewater technology, especially membrane technology for end-of-pipe treatment, significantly improved in China.

Moreover, we observed the unique result that the capacity for industrial wastewater treatment does not significantly affect the efficiency of wastewater management. However, the wastewater abatement cost significantly contributes to improving all three efficiencies. One interpretation of this surprising result is the low operational ratio of treatment facilities. According to Han et al. [14], "for many enterprises, costs of sewage treatment and pollution control technology have been

prohibitive, and in combination with the weak regulatory regime, have fostered a culture which has long tolerated unregulated discharge of pollution." Thus, while industry firms established treatment facilities following governmental policy, they had little incentive to operate these facilities appropriately because of the high treatment costs.

Table 3. Results of the determinant analysis of wastewater management efficiency.

	Wastewater Reuse Efficiency			COD Management Efficiency			NH$_3$-N Management Efficiency		
	Coef.	z-Value		Coef.	z-Value		Coef.	z-Value	
COD target				0.114	2.6	***			
NH$_3$-N target							0.091	2.36	**
Foreign	0.019	5.13	***	0.016	3.81	***	0.012	3.01	***
Polluted	0.002	0.42		0.001	0.14		−0.002	−0.48	
Capacity	0.001	0.23		−0.002	−0.58		−0.003	−0.75	
Abatement	0.086	3.74	***	0.058	2.13	**	0.076	2.78	***
West x Foreign	0.109	4.50	***	0.052	1.82	*	0.059	2.03	**
West x Polluted	−0.025	−1.08		−0.033	−1.24		−0.046	−1.73	*
West x Capacity	−0.01	−0.66		−0.015	−0.93		−0.011	−0.71	
West x Abatement	−0.024	−0.46		0.003	0.05		0.058	0.97	
Constant	0.2	2.48	**	0.137	1.77	*	0.245	3.15	***
Number of observations	341			341			341		
chi-square	143.4			82.7			92.76		
Prob > chi-square	0.00			0.00			0.00		
Log likelihood	−75.38			−123.32			−117.41		

Note 1: * indicates significant at the 10% level, ** indicates significant at the 5% level, and *** indicates significant at the 1% level. Note 2: The western region dummy (West) is equal to one if a province is located in the western region (see Supplementary Material).

Finally, we investigated the main determinants of the efficiency gaps within the western region using cross terms based on the western region dummy and the four determinant variables. As shown in Table 3, the cross term of total investment by foreign-funded companies significantly increased efficiency. This result implies that investment by foreign-funded companies is a key determinant of the industrial wastewater management efficiency.

Additionally, we observed that the cross term of the production scale of high water pollution intensity products affects NH$_3$-N management efficiency at the 10% significance level. Therefore, a change in the production scale of high water-polluting products is another important factor to consider in NH$_3$-N management.

Based on these results, we verified that the key determinants of wastewater management efficiency are different for different pollutants. This finding suggests that the Chinese government should establish economic incentives and environmental policies to improve efficiency by expanding investment by foreign-funded companies and increasing pollution abatement costs for industrial wastewater.

5. Conclusions and Policy Implications

5.1. Conclusions

This study analyzed the wastewater management efficiencies of Chinese industrial sectors from 2004 to 2014 using the pooled WRDDM approach, focusing particularly on COD and NH$_3$-N emissions. Additionally, we investigated the determining factors of wastewater management efficiency using an econometric model. The conclusions can be summarized as follows.

First, the industrial sectors located in the eastern and central areas improved their wastewater management efficiency. Additionally, a large gap in wastewater management efficiency was observed within provinces in the western region. Second, investment by foreign-funded companies and

industrial wastewater abatement costs were identified as the main determinants of wastewater management efficiency.

Third, we found that the determinants of wastewater treatment performance differ among both provinces and wastewater pollutant substances. In particular, production-scale expansion of high water pollution intensity products weakly but significantly decreased NH_3-N management efficiency in the western region. This result implies that we can better understand the effects of wastewater pollution abatement policies aimed at specific pollutants by considering provincial characteristics.

5.2. Policy Implications

Currently, the Chinese government designs environmental policies and provides subsidies to encourage industrial firms to prevent or manage wastewater pollution. Specifically, a water pollution prevention and control action plan (the Water Ten Plan) was released as an ambitious plan for water management by the Chinese government in 2015. Han et al. [14] noted that the Water Ten Plan is arguably the most comprehensive policy to date that is designed to tackle the pollution of water resources. However, it is difficult to determine how and whether these policies will motivate industrial sectors to better treat their wastewater pollution because the provinces have various motivations and limitations regarding wastewater treatment activities [26]. Therefore, this research framework and the application of the wastewater abatement performance evaluation model used in this study could be helpful for clarifying the driving factors in Chinese wastewater treatment and could contribute to establishing effective environmental policies.

Policy recommendations can be derived from our results. Notably, investment by foreign-funded companies can improve the wastewater management efficiency in the western region much more than in other regions. This regional difference indicates that increasing the opportunity for foreign investment in western regions may be an effective strategy to improve the national wastewater management efficiency in China.

This study also has important policy implications regarding differential policies at the regional level. Foreign companies have mainly invested in the eastern provinces because of the business-friendly markets and low taxes in special economic zones [27]. In contrast, the western region has developed based on conventional industries, including high pollution intensity sectors, which coincide with decreased environmental efficiency [20]. Given the gaps between the western and eastern regions and considering the diverse characteristics of the development patterns and wastewater management outcomes, the Chinese government should allow local governments more discretion to establish wastewater management policies based on regional situations and targets.

Further research should investigate the process of wastewater management improvement due to investment by foreign-funded companies and pollution abatement costs, which were identified as the main determinant factors for improvements in industrial wastewater treatment.

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References

1. Shang, Y.; Wang, J.; Ye, Y.; Lei, X.; Gong, J.; Shi, H. An analysis of the factors that influence industrial water use in Tianjin, China. *Int. J. Water Resour. Dev.* **2017**, *33*, 81–92. [CrossRef]

2. Fujii, H.; Managi, S.; Kaneko, S. A water resource efficiency analysis of the Chinese industrial sector. *Environ. Econ.* **2012**, *3*, 82–92.

3. Cai, J.; Varis, O.; Yin, H. China's water resources vulnerability: A spatio-temporal analysis during 2003–2013. *J. Clean. Prod.* **2017**, *142*, 2901–2910. [CrossRef]

4. Guardian. Four-Fifths of China's Water from Wells 'Unsafe Because of Pollution', 2016. Available online: https://www.theguardian.com/environment/2016/apr/12/four-fifths-of-chinas-water-from-wells-unsafe-because-of-pollution (accessed on 17 May 2017).

5. Wang, Q.; Yang, Z.-M. Industrial water pollution, water environment treatment, and health risks in China. *Environ. Pollut.* **2016**, *218*, 358–365. [CrossRef] [PubMed]

6. Lu, Y.; Song, S.; Wang, R.; Liu, Z.; Meng, J.; Sweetman, A.J.; Jenkins, A.; Ferrier, R.C.; Li, H.; Luo, W.; et al. Impacts of soil and water pollution on food safety and health risks in China. *Environ. Int.* **2015**, *77*, 5–15. [CrossRef] [PubMed]

7. Tao, T.; Xin, K. Public health: A sustainable plan for China's drinking water. *Nature* **2014**, *511*, 527–528. [CrossRef] [PubMed]

8. Tortajada, C. Policy dimensions of development and financing of water infrastructure: The cases of China and India. *Environ. Sci. Policy* **2016**, *64*, 177–187. [CrossRef]

9. Wang, Y.; Chen, C.; Araral, E. The effects of migration on collective action in the commons: Evidence from rural China. *World Dev.* **2016**, *88*, 79–93. [CrossRef]

10. Shao, W. Effectiveness of water protection policy in China: A case study of Jiaxing. *Sci. Total Environ.* **2010**, *408*, 690–701. [CrossRef] [PubMed]

11. Jia, J.; Jian, H.; Xie, D.; Gu, Z.; Chen, C. Multi-perspectives' comparisons and mitigating implications for the COD and NH_3-N discharges into the wastewater from the industrial sector of China. *Water* **2017**, *9*, 201. [CrossRef]

12. National Bureau of Statistics, China Statistical Yearbook on Environment, Ministry of Environmental Protection. Available online: http://www.stats.gov.cn/ztjc/ztsj/hjtjzl/ (accessed on 18 June 2017). (In Chinese)

13. Li, T.; Han, Y.; Li, Y.; Lu, Z.; Zhao, P. Urgency, development stage and coordination degree analysis to support differentiation management of water pollution emission control and economic development in the eastern coastal area of China. *Ecol. Indic.* **2016**, *71*, 406–415. [CrossRef]

14. Han, D.; Currell, M.J.; Cao, G. Deep challenges for China's war on water pollution. *Environ. Pollut.* **2016**, *218*, 1222–1233. [CrossRef] [PubMed]

15. Zhu, S.; He, C.; Liu, Y. Going green or going away: Environmental regulation, economic geography and firms' strategies in China's pollution-intensive industries. *Geoforum* **2014**, *55*, 53–65. [CrossRef]

16. Wang, Y.; Ching, L. Institutional legitimacy: An exegesis of normative incentives. *Int. J. Water Resour. Dev.* **2013**, *29*, 514–525. [CrossRef]

17. Fujii, H.; Managi, S.; Kaneko, S. Wastewater pollution abatement in China: A comparative study of fifteen industrial sectors from 1998 to 2010. *J. Environ. Protect.* **2013**, *4*, 290–300. [CrossRef]

18. Barros, C.P.; Managi, S.; Matousek, R. The technical efficiency of the Japanese banks: Non-radial directional performance measurement with undesirable output. *Omega* **2012**, *40*, 1–8. [CrossRef]

19. Chen, P.C.; Yu, M.M.; Chang, C.C.; Hsu, S.H.; Managi, S. Non-radial directional performance measurement with undesirable outputs: An application to OECD and non-OECD countries. *Int. J. Inf. Technol. Dec. Mak.* **2015**, *14*, 481–520. [CrossRef]

20. Fujii, H.; Cao, J.; Managi, S. Decomposition of productivity considering multi-environmental pollutants in Chinese industrial sector. *Rev. Dev. Econ.* **2015**, *19*, 75–84. [CrossRef]

21. National Bureau of Statistics, China Statistical Yearbook, China Statistics Press, Beijing, China. Available online: http://www.stats.gov.cn/english/Statisticaldata/AnnualData/ (accessed on 18 June 2017).

22. Managi, S.; Kaneko, S. Environmental performance and returns to pollution abatement in China. *Ecol. Econ.* **2009**, *68*, 1643–1651. [CrossRef]

23. Kaneko, S.; Fujii, H.; Sawazu, N.; Fujikura, R. Financial allocation strategy for the regional pollution abatement cost of reducing sulfur dioxide emissions in the thermal power sector in China. *Energ. Policy* **2010**, *38*, 2131–2141. [CrossRef]

24. Wu, H.; Guo, H.; Zhang, B.; Bu, M. Westward movement of new polluting firms in China: Pollution reduction mandates and location choice. *J. Comp. Econ.* **2017**, *45*, 119–138. [CrossRef]

25. Zheng, X.; Zhang, Z.; Yu, D.; Chen, X.; Cheng, R.; Min, S.; Wang, J.; Xiao, Q.; Wang, J. Overview of membrane technology applications for industrial wastewater treatment in China to increase water supply. *Resour. Conserv. Recy.* **2015**, *105*, 1–10. [CrossRef]

26. Asia Development Bank. *Addressing Water Security in the People's Republic of China: The 13th Five-Year Plan (2016–2020) and Beyond*; Asia Publishing Development Bank: Manila, Philippines, 2016.

27. Cai, X.; Lu, Y.; Wu, M.; Yu, L. Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. *J. Dev. Econ.* **2016**, *123*, 73–85. [CrossRef]