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THE MEASUREMENT AND ANALYSIS OF TOTAL-FACTOR WATER EFFICIENCY IN INDUSTRY OF CHINA

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Abstract. *In this paper, we describe the development of a four-stage data envelopment analysis (DEA) model to resolve total-factor water efficiency (TFWE) into total-factor water managerial efficiency (TFWME) and total-factor water environmental efficiency (TFWEE). We conducted empirical analysis of the TFWE in the provincial industry of China for the years 2001-2012. The research showed that the overall TFWE was still at a lower level in the industry of China and the water saving potential was approximately 30% to 40% of the water consumption. Suggested reasons for the lower observed water efficiency include inefficient water resource management and poor environments. At present, improvements in water efficiency mainly depend on improvements in the external environment, and there is a lack of motivation for enhancing the internal water managerial efficiency. The TFWE, TFWME and TFWEE values showed obvious regional characteristics, where eastern China was leading in water efficiency and northeastern China was regressing. The key factors that were determined to affect the regional TFWEE included the industrial structure, wastewater treatment capacity, and technology improvement level and water price. To improve the respective regional water efficiencies, Beijing, Tianjin, Shanghai and Hainan should focus on improving industrial water resource management; Guangdong, Guizhou, Henan and Ningxia should focus on optimizing their external environment and Hebei, Shanxi, Jilin and other regions should improve water resource management and the environment.*
Keywords: Four-stage DEA model, Total-factor water efficiency, Total-factor water managerial efficiency, Total-factor water environmental efficiency, Industry

1. Introduction.

Although water resources are important for protecting human production and life, industrial production processes require the use of water. For example, the consumption of industrial water accounts for approximately 1/4 of the total water consumption in China every year (calculated according to China Statistical Yearbooks). In many countries, the water supply is far lesser than the demand, and this problem is particularly serious in China where the rate of industrialisation is rapidly increasing. There are two ways to solve this problem: the first is to characterise the current water supply and increase it if possible and the second is to strengthen the water management demand and improve the efficiency in the use of water resources. An increasing number of studies have shown that the second method is the most effective way to solve the problem [1-3].

Two key problems must be solved to explore strategies for improving the water efficiency. The first is how to scientifically measure the water efficiency. Is the ratio of water input to economic output appropriate? How can the water efficiency be formulated in a more reasonable way? The second problem is how to find the appropriate factors that affect the overall water efficiency as there are many factors that affect the water use efficiency. The correct perspective is required to explore these internal and external factors and to determine the importance of these factors for the efficient use of water in order to propose strategies to improve the utilisation efficiency of water. This paper offers some theoretical improvements. For example, it addresses the issue of total-factor water efficiency and considers the water efficiency with various inputs. The water efficiency measurement method solves the theoretical problem that the allocation of water and other resources could not be combined in a single-factor water efficiency measurement method; this method cannot provide effective guidance for reasonable use of water resources in practical use. However, the multifactor water efficiency measurement method is more suitable for practical production and can provide scientific guidance for effective use of water resources.

This paper is arranged as follows: Section 2 contains a summary of the relevant research, Section 3 describes the model and methods, Section 4 explains the variable selection, sample selection and data sources, Section 5 contains an analysis of the empirical results and discussions and Section 6 presents the conclusions.

2. **Literature Review.** The overall water resources efficiency is related to the water resources production efficiency and the water resource use efficiency. The water resources production efficiency mainly refers to the supply efficiency of waterworks and wastewater treatment plants, and the water resource use efficiency is related to the water use efficiency of each sector of the national economy and the residents in the many processes that use water. This paper studied the green total-factor water efficiency that belongs to the water resource use efficiency. Research of the water resource use efficiency is commonly divided into two factors: the single-factor water efficiency and the total-factor water efficiency.

The single-factor water efficiency usually refers to the ratio of the water input to its production output. This more common evaluation indicator is often used in agriculture to evaluate the effect of the water input. Li and Barker (2004), Bouman and Gregg (2007) and Gross (2007) formulated an indicator of the single-factor water efficiency to measure the economic value of water [1-3], which is the ratio of the agricultural water input to the output of an agricultural product. This measurement method is simpler and has been extended to measure the water efficiency at a more macro level. For example, some scholars have used the ratio of water input to the economic value produced by the water input as the water efficiency. Statyukha et al. (2009) used the method to measure the water efficiency of a region or industry [4]. This index has also been used by some governmental statistics departments; for example, the National Bureau of Statistics of China has used the water consumption for every 10,000 yuan of GDP or per 10,000 yuan of industrial added value to measure the water efficiency in different regions or industries. However, some researchers have considered the ecological value of the water resources when attempting to formulate the single-factor water efficiency; for example, Renault and Wallender (2000) used the ratio of every unit input of water to the related production of crop nutrition (such as energy, vitamins and glucose) as a water productivity index [5]. These indexes of the single-factor water efficiency are somewhat complex to measure and only reflect the ecological benefits of the water resources, not the economic benefits and the green efficiency.

The total-factor water efficiency (TFWE) refers to the ratio of the efficient water input amount to the actual water input amount, which is based on a comprehensive consideration of other factor inputs. There are two main methods for calculating the TFWE: the data envelopment analysis (DEA) method and the stochastic frontier analysis (SFA) method. At present, a majority of scholars have used the DEA method to measure the TFWE. Hu et al. (2006) first formulated a TFWE model based on the DEA method, and the model considered the efficient allocation of the water input and other factor inputs in a production process [6]. In this case, the calculated water efficiency does not only relate to a single-factor input and the output as other factors are considered as inputs. The water efficiency obtained through the allocation of the water input and other factors as inputs results in a water efficiency that is a kind of allocation efficiency. The measurement method of the TFWE has been widely used. In recent years, some scholars have used the DEA model of the non-expected output based on the Hu et al.'s total-factor model to measure the TFWE by considering environmental pollution. For example, Zhang and Zhong (2015) chose factors including labour, capital, agricultural materials, irrigation water uptake, ecological burden, pollution discharges and the grain yield of the nation and its 31 provinces from 2004 to 2013 [7], and they respectively used material flow analysis (MFA), SFA and DEA methods to measure the productivity of irrigation water resources, technical efficiency and total-factor resources efficiency. Karagiannis et al. (2003) established an SFA model of measuring the water efficiency and included factors that affected the water efficiency into the model [8]. This particular method obtained the support of some scholars; for example, Kaneko et al. (2004) studied the water efficiency in China's agricultural production [9], Chen and Bai (2013) used the SFA method to measure the TFWE in China's industry [10], and Geng et al. (2014) used the SFA method to measure the water efficiency of irrigation methods [11]. However, this method has not been widely used because it cannot effectively solve the multi-output problem.

The water efficiency is affected by many factors. Many researchers believe that strengthening the demand side management is important; for example, Gregg et al. (2006), Sharpe et al. (2015) and Kurle et al. (2015) reported that the water-saving technological improvement in the demand side management is very important [12-14]. Deng et al. (2006) reported that the water-saving irrigation technology is an important factor to enhance the efficiency of agricultural water resources in China [15]. Chemak (2012) considered that the technology performance and the water use efficiency of the demand side are key factors affecting the agricultural irrigation water use efficiency [16]. Lopez-Gunn et al. (2012), Sahin et al. (2015) and Wang et al. (2014) analyzed the problems of water resources allocation [17-19], economic development and population growth in the demand side, and these problems reportedly affected the water resource use efficiency. Budiyanto (2014) and Oduol et al. (2011) thought that the promotion of advanced irrigation technology, cultivation of high value crops and changes in crop growth and harvest time could enhance the efficiency of agricultural water resources [20,21]. Stoughton (2015) proposed to improve the water efficiency by evaluating, demonstrating and training and financially supporting water-saving technologies [22], whereas Graymore and Wallis (2010) considered the users' attitudes toward water saving and their water-saving behaviour on the demand side; for example [23], farmers may improve the water resource use efficiency for economic incomes, while hobby farmers and residential users may save water for altruistic reasons.

This paper took a different approach from the above research by formulating a DEA model including labour, capital, energy, water resources and economic output factors. The model not only measured the comprehensive total-factor water resource use efficiency but also divided the TFWE into the total-factor water managerial efficiency (TFWME) and the total-factor water environmental efficiency (TFWEE). In this model, the external environmental factors and internal management factors were separated when considering the TFWE. Based on the perspective of 'environment-management', we could clearly find the roots of water use inefficiency and thus obtain more reliable methods to enhance the water resource use efficiency. Unlike the research perspectives of Yu et al. (2008), Kang et al. (2002) and Mo et al. (2009) [24-26], this paper focused on water efficiency factors and water efficiency improvement in China's industrial sector. This paper differs from previous research and offers three new contributions. First, it analyzes the external factors that affect the total-factor water efficiency and the results. Second, it divides the total-factor water efficiency into total-factor water management efficiency and total-factor water environmental efficiency; weaknesses are highlighted and a scientific method to improve the total-factor water efficiency in China is described. Third, a comprehensive analysis and comparison of the total-factor water efficiency of each province of China is provided, and important ways of improving the total-factor water efficiency of each province are proposed.

3. Model Formulation and Analysis.

3.1. Description of the four-stage DEA evaluation model.

Fried et al. (1999) proposed the four-stage DEA model and suggested that a production unit's transformation capacity of changing inputs into outputs is not only affected by the technical efficiency [27], but also affected by the external operating environment. The core idea of the four-stage DEA model is to use the non-parametric linear programming method from the frontier estimation method to control the exogenous operating environment variables, eliminate the effects of exogenous environment variables on the technical efficiency and evaluate the decision making unit's managerial efficiency based on the equalisation of the external environment. The specific principles and steps of the four-stage DEA model are described as follows.

In the first stage, calculations are performed on the raw data in the DEA model. There are two types of DEA models: input-oriented and output-oriented, which solve the same problem from different points of view. Compared to outputs, inputs are basic decision variables that are easier to control [28]. Therefore, this paper chose the input-oriented, variable returns to scale BCC model, which is described as follows:

$$\min\ \theta_j$$
$$\text{s.t.} \begin{cases} \sum_{j=1}^{N} \lambda_j X_j + s^+ = \theta_j X_j \\ \sum_{j=1}^{N} \lambda_j X_j + s^- = Y_j \\ \sum_{j=1}^{N} \lambda_j = 1 \\ \lambda_j \geq 0,\ s^+ \geq 0,\ s^- \geq 0,\ j = 1, 2, \ldots, N \end{cases} \tag{1}$$

where X and Y represent the input and output, respectively. We observed that provinces with good external environments had a lower input amounts than provinces with worse external environments in industrial production; thus, the former had a better efficiency. Thus, the DEA model could not separate the impact of the external environment on the efficiency at this stage.

In the second stage, the exogenous variables were identified and the influence factor model was constructed. The variable i was chosen as the exogenous environmental variable and (Z_i) as the explanatory variable. Based on the results of the first stage, the decision making unit k's jth input slack variable S_{kj}^+ was taken as the response variable and a quantitative evaluation of the impact of the exogenous environmental variable on the input slack variable or output surplus variable was made. The model is defined as follows:

$$S_{kj}^+ = f_{kj}(Z_{kj}, \beta_{kj}, w_{kj}), \quad j = 1, \ldots, N, \quad k = 1, \ldots, K \tag{2}$$

where Z_{kj} and β_{kj} represent the kth environmental variable and the parameter of the jth province of China, respectively.

The third stage involved the adjustment of the raw data. According to the estimation results of the second stage, we adjusted all of China's provinces to the worst external environment. The sample unit that had a favourable environment was now 'punished' to add additional inputs to obtain the adjusted input X'. The calculation method is as follows:

$$X_j' = X_j + \left[\max_j \left\{ f\left(Z_i; \hat{\beta}_i\right)\right\} - f\left(Z_i; \hat{\beta}_i\right)\right] + \left[\max_j \left\{\hat{v}_k\right\} - \hat{v}_k\right] \tag{3}$$

In the fourth stage, the DEA model was calculated after adjustment of the data. We used the X' value calculated in the third stage to replace X, applied the standard DEA-BCC model again, appraised the adjusted input and output data and obtained the total-factor managerial efficiency of the province in China.

3.2. Measurement and analysis of the total-factor water efficiency.

3.2.1. *Total-factor water efficiency.* According to Hu et al. (2006), the TFWE is defined as the ratio of the target value of water consumption to the actual value of water consumption. The target value of water consumption is calculated on the basis of the original input and output data, and it is the difference of the actual water input value and the input slack variable [6].

The target value of water consumption is the minimum consumption of water resources at the current output, and it is not greater than the actual value of water consumption such that the TFWE is an index ranging between 0 and 1. If a province does not have an input slack variable, its TFWE is equal to 1 and it shows that the province is an efficient user of water resources. If a province's target value of water is far below the actual value of water, it shows that the province's TFWE tends to zero and the province has a very low level of water use.

3.2.2. *Total-factor water managerial efficiency.* In the four-stage DEA model, the second stage involves the identification of the environmental factors, the third stage achieves equalisation of the environment and obtains the adjusted actual value of water consumption (X_W'') and the fourth stage obtains the adjusted target value (X_W''') based on the evaluation of input and output data. According to the formulating principle of the indicator of the TFWE, this paper formulated the total-factor water managerial efficiency (TFWME), and its measurement formula is as follows:

$$TFWME = \frac{X_W''}{X_W'''} \tag{4}$$

The main difference between the TFWME and TFWE is that the TFWME is based on controlling the exogenous environmental variables to achieve an environmental equalisation while excluding the inefficiency due to the environmental differences of the provinces. Therefore, the TFWME shows the pure water managerial efficiency of the provinces.

3.2.3. *Total-factor water environmental efficiency.* In this paper, the difference between the TFWE and TFWME was classified as the environmental factor. We referred to the calculation method of Li. To identify the relations of the total-factor water environmental efficiency (TFWEE) [29], TFWE and TFWME, we calculated the TFWEE as follows:

$$TFWEE = \frac{TFWE}{TFWME} \tag{5}$$

The TFWEE is different from the TFWE and the TFWME as it is not limited to a range of 0 to 1. If the TFWEE $>$ 1, the TFWE of the province is at an environmental advantage where the water inefficiency is mainly associated with the management factors, and the environmental factors can offset the inefficient management of water resources to a certain extent. If the TFWEE < 1, then the TFWE of the province is at an environmental disadvantage and the environmental factors are an important source of the water resources inefficiency. If the TFWEE = 1, then the regional TFWE is the same as the TFWME and the environment has no obvious effect on the water efficiency.

4. The Variable Selection, Sample Selection and Data Sources.

4.1. Selection of the environment variables. Water resources are influenced by water demand increases, the global depletion of water resources, water prices and other factors and are thus important production factors that may be included in the Cobb-Douglas production function. For example, Wang and Lall (2002) used water resources as inputs in the production function [30]. Based on this concept, the current paper used labour, capital, energy and water resources as the input factors and selected the gross domestic product (GDP) as the output factor.

In the four-stage DEA model, we need to select several environmental factors that may affect the TFWE in the second stage. Based on prior research results [6,29], this paper used the industrial structure, environmental regulations and the water price as environmental factors that could affect the TFWE. The indicators of inputs, outputs and environmental variables are shown in Table 1.

TABLE 1. Description of the indicators used as inputs, outputs and environment variables in the model

	Variables	Specific indicators (unit)
Input factor	Labour	Industrial employment (number of people)
	Capital	Industrial capital stock (100 million yuan)
	Energy	Total energy consumption in industry (10000 tonnes)
	Water	Industrial water use (100 million cubic metres)
Output factor	Gross industrial output	Gross industrial output value (100 million yuan)
Environmental factors	Industrial structure	The proportion of the secondary industry in the national economy (%)
	Industrial wastewater treatment level	Annual industrial wastewater treatment capacity/annual industrial waste water
	Industrial technological improvement level	Expense for industrial technological improvement/gross output value
	Water price	Industrial water prices of regions (yuan/cubic metre)

4.2. Sample selection and data sources. This study selected China's 30 provinces as the research objects and did not consider Tibet due to missing data. The study obtained data from the provinces (including municipalities directly under the control of the central government and autonomous regions) from 2000 to 2012 as samples. The industrial output values and employment numbers were obtained from the China Industrial Economy Statistical Yearbook, and the energy consumption data were obtained from the China Energy Statistical Yearbook. The total investment in industrial pollution control, regional industrial water use amounts and water use prices were obtained from the China Statistical Yearbook on Environment, China Water Statistical Yearbook and China Water Resources Bulletin, respectively. The regional GDP for a given year was calculated

TABLE 2. Statistical description of the sample data used as the inputs, outputs and environmental variables

Variable	Unit	Mean	Standard deviation	Kurtosis	Skewness
Labour	ten thousand people	2174.53	1533.29	1.006	1.231
Capital	one hundred million yuan	20397.32	15721.95	4.557	0.321
Energy	ten thousand tonnes	10452.73	6747.83	0.119	2.558
Water	one hundred million cubic metres	225.65	11.647	0.773	−0.234
Total industrial output	one hundred million yuan	4357.68	338.7	1.883	−0.954
Industry structure	%	33.500	22.51	2.127	0.006
Industrial wastewater treatment level	%	18.1	2.2	0.661	1.882
Industrial technological improvement level	%	7.2	3.3	1.872	1.432
Water price	yuan/cubic metre	2.412	1.647	1.772	0.227

by using the year 2000 as the base year to eliminate the impact of inflation. The common method for measuring the capital input is the perpetual inventory method, which estimates the capital stock according to a constant price after the estimation of a base year capital stock; i.e., $K_t^j = K_{t-1}^j + I_t^j - D_t^j$, $j = 1, 2, 3, \ldots, 28$, $t = 2000, \ldots, 2012$, where K_t^j represents the capital input of the jth province in the tth year, K_{t-1}^j represents the industrial capital input of the jth province in the $t-1$th year, I_t^j represents the amount of new increase capital of the jth province in the tth year and D_t^j represents the amount of the capital depreciation of the jth province in the tth year (Zhang et al., 2004) [31]. The statistical description of the sample data used in this study is shown in Table 2.

5. Results.

5.1. Comprehensive evaluation of the industrial TFWE in China.

From 2001 to 2012, the industrial TFWE displayed a slow upward trend (Table 3). In 2001, the average value of national TFWE was 0.622, whereas in 2012, the average value was 0.692, with an average annual growth rate of less than 2%. The data also showed that the water saving potential was quite large, where the maximum water saving could be approximately 30% to 40% of the water consumption at the same production level. In China, the TFWE showed characteristics of regional development. In total, 4 provinces, Beijing, Shanghai, Tianjin and Hainan, were closer to the efficient frontier value of 1, and the majority of provinces with higher efficiencies were located in eastern China where the economy was more developed.

From 2001 to 2012, the regional TFWE of the four major regions of China was observed to increase (Figure 1). The eastern part of China is the most developed region and had the highest observed TFWE with values ranging from 0.75 to 0.80. The western region and

TABLE 3. Total-factor water efficiency (TFWE) of the provinces in China from 2001 to 2012

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Anhui	0.513	0.514	0.515	0.516	0.543	0.545	0.547	0.549	0.563	0.583	0.584	0.603
Beijing	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Chongqing	0.505	0.506	0.507	0.508	0.535	0.537	0.539	0.541	0.555	0.575	0.576	0.575
Fujian	0.521	0.522	0.523	0.524	0.551	0.553	0.555	0.557	0.571	0.591	0.592	0.601
Gansu	0.627	0.628	0.629	0.630	0.657	0.659	0.661	0.663	0.677	0.697	0.698	0.697
Guangdong	0.636	0.637	0.638	0.639	0.666	0.668	0.670	0.672	0.686	0.706	0.707	0.726
Guangxi	0.587	0.588	0.589	0.590	0.617	0.619	0.621	0.623	0.637	0.657	0.658	0.657
Guizhou	0.630	0.631	0.632	0.633	0.660	0.662	0.664	0.666	0.680	0.700	0.701	0.720
Hainan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	0.538	0.539	0.540	0.541	0.578	0.580	0.582	0.584	0.578	0.598	0.599	0.598
Heilongjiang	0.507	0.508	0.509	0.510	0.537	0.539	0.541	0.543	0.557	0.577	0.578	0.597
Henan	0.511	0.512	0.513	0.514	0.541	0.543	0.545	0.547	0.561	0.581	0.582	0.601
Hubei	0.500	0.501	0.502	0.503	0.530	0.532	0.534	0.536	0.550	0.570	0.571	0.570
Hunan	0.543	0.544	0.545	0.546	0.573	0.575	0.577	0.579	0.593	0.613	0.614	0.613
Jiangsu	0.599	0.600	0.601	0.602	0.629	0.631	0.633	0.635	0.649	0.669	0.670	0.659
Jiangxi	0.543	0.544	0.545	0.546	0.573	0.575	0.577	0.579	0.593	0.613	0.614	0.612
Jilin	0.503	0.504	0.505	0.506	0.533	0.535	0.537	0.539	0.553	0.573	0.574	0.583
Liaoning	0.516	0.517	0.518	0.519	0.546	0.548	0.550	0.552	0.566	0.586	0.587	0.606
Inner Mongolia	0.606	0.607	0.608	0.609	0.636	0.638	0.640	0.642	0.656	0.676	0.677	0.696
Ningxia	0.606	0.607	0.608	0.609	0.636	0.638	0.640	0.642	0.656	0.676	0.677	0.696
Qinghai	0.637	0.638	0.639	0.640	0.667	0.669	0.671	0.673	0.687	0.707	0.708	0.710
Shandong	0.589	0.590	0.591	0.592	0.619	0.621	0.623	0.625	0.639	0.659	0.660	0.677
Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shaanxi	0.597	0.598	0.599	0.600	0.627	0.629	0.631	0.633	0.647	0.667	0.668	0.687
Shanxi	0.600	0.601	0.602	0.603	0.630	0.632	0.634	0.636	0.650	0.670	0.671	0.680
Sichuan	0.547	0.548	0.549	0.550	0.577	0.579	0.581	0.583	0.597	0.617	0.618	0.637
Tianjin	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	0.626	0.627	0.628	0.629	0.656	0.658	0.660	0.662	0.676	0.696	0.697	0.696
Yunnan	0.463	0.464	0.465	0.466	0.493	0.495	0.497	0.499	0.513	0.533	0.534	0.553
Zhejiang	0.623	0.624	0.625	0.626	0.653	0.655	0.657	0.659	0.673	0.693	0.694	0.703
National	0.622	0.623	0.624	0.625	0.649	0.651	0.652	0.654	0.665	0.683	0.684	0.692

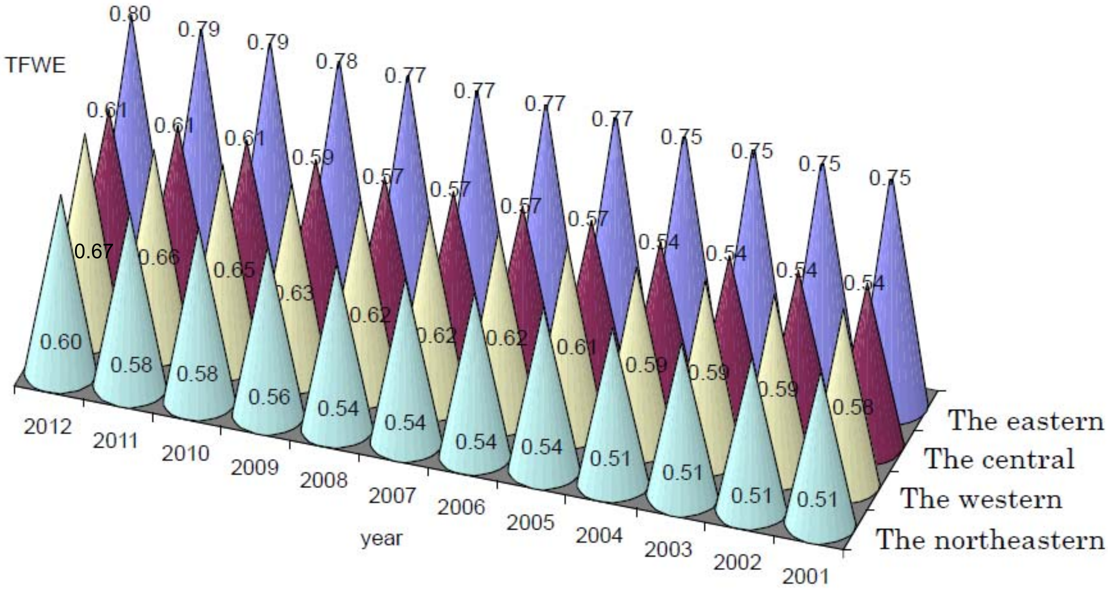

FIGURE 1. Total-factor water efficiencies (TFWEs) in the four major regions of China (2001-2012)

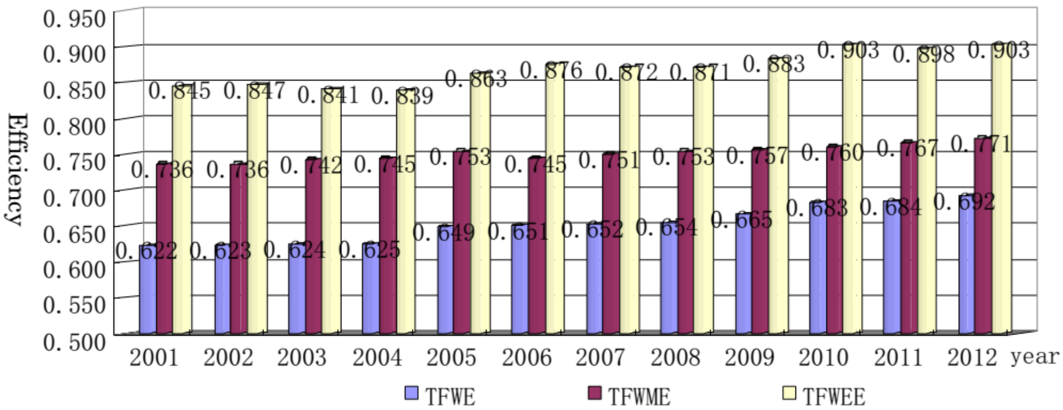

FIGURE 2. Changes of the total-factor water efficiency, total-factor water managerial efficiency, and total-factor water environmental efficiency in China (2001-2012)

the central region had the second and third highest observed TFWE, with the western region TFWE ranging from 0.58 to 0.67 and the central region TFWE ranging from 0.54 to 0.61. The TFWE in the northeastern region was the lowest with values ranging from 0.51 to 0.60, and these values were only 20% to 25% of the TFWE of the eastern region. Regarding the water saving potential, in 2012 the maximum water saving could be approximately 20% of the water consumption in the eastern region, 33% in the western region, 39% in the central region and 60% in the northeastern region (Figure 1).

5.2. **Results of TFWME and TFWEE analysis.** As shown in Figure 2, the TFWME in China was significantly higher than the TFWE. From 2001 to 2012, China's TFWME ranged from 0.736 to 0.771, while over the same period the TFWE ranged from 0.622 to 0.692. On the whole, the external environment had a negative effect on China's TFWE. From 2001 to 2012, China's TFWEE was < 1 with values ranging from 0.839 to 0.903.

In general, the managerial efficiency of a decision making unit with an environmental advantage will be overestimated and the efficiency of a decision making unit with an environmental disadvantage will be underestimated if we do not eliminate the environmental differences and use the TFWE to evaluate the water managerial efficiency, which will eventually produce an error evaluation. By separating the TFWE into the TFWEE and TFWME, we eliminated the environmental impact in the evaluation of the TFWME. In this case, the underestimation or overestimation of the managerial efficiency caused by environmental differences will disappear, and the differences of the regional TFWME will be lower than the differences of the TFWE. Based on the results of the current study, the low efficiency of water resources in China was apparently caused by environmental and management inefficiencies. The internal management and external environment thus need to be improved to promote the water resources efficiency.

From a dynamic perspective, the TFWE, TFWME and TFWEE showed fluctuating growth trends from 2001 to 2012, though the growth rates were small with average annual growth rates of 0.972%, 0.428% and 0.617%, respectively. Based on the data, the TFWME increased slowly; thus, the improvement of the TFWE was mainly due to the improvement of the exogenous environment variables. The optimisation of the industrial structure, strengthening of environmental regulations and reasonable adjustments of water prices are the generally used methods for improving the water efficiency. Because the water resource management level did not rapidly increase, the results suggested that there was a lack of internal impetus to improve the water efficiency in the regions, which will not help to achieve the goal of energy savings and discharge reduction to achieve sustainable development in China. Because the rapid increase in industrialisation has resulted in a rapid increase in the demand for water resources and the rising dependence for outside water resources, the problems of regional water resource management and decreasing water resources efficiency need to be urgently solved.

5.3. **Evaluation of the regional differences in the TFWME and TFWEE.** From 2005 to 2009, the TFWME in China was between 0.6 and 0.9 and displayed a slowly declining trend. At the same time, the TFWME displayed obvious regional characteristics. The eastern region had the highest TFWME values, while the northeastern region had the lowest values with the western and central regions having values in the middle (Table 4).

At the same time, the TFWEE had a fluctuating but increasing trend, which indicated that the environment had been improved and the inefficiency caused by the environment had gradually improved. Specifically, the TFWEE in the eastern region was close to 1 and this region had a relatively good external environment. The results indicated that the eastern region not only had better water resource management, but also better industrial structure, more complete environmental regulations, reasonable water prices and other advantages for environmental development. The TFWEE of the northeastern, central and western regions was lower than the eastern region's efficiency and there were obvious gaps as the TFWEE in the northeastern region had rapid growth, while the central region growth was relatively slow.

From the above results, we determined that the water resources inefficiency of the eastern region mainly came from the managerial inefficiency; thus, the improvement of the water efficiency would mainly depend on enhancing the managerial efficiency. In contrast, the central, western and northeastern regions of China should pay attention not only to water management but also to improvements in the external environment.

Table 4. Total-factor water managerial efficiency (TFWME) and total-factor water environmental efficiency (TFWEE) in the four regions of China

	TFWME				TFWEE			
Year	western	northeastern	central	eastern	western	northeastern	central	eastern
2001	0.711	0.662	0.692	0.824	0.824	0.771	0.777	0.943
2002	0.714	0.665	0.694	0.816	0.822	0.770	0.776	0.952
2003	0.716	0.670	0.697	0.830	0.821	0.765	0.774	0.936
2004	0.718	0.672	0.700	0.834	0.821	0.764	0.773	0.933
2005	0.732	0.691	0.701	0.837	0.845	0.781	0.810	0.949
2006	0.731	0.629	0.704	0.829	0.849	0.871	0.809	0.959
2007	0.733	0.633	0.708	0.842	0.849	0.868	0.808	0.946
2008	0.733	0.635	0.711	0.848	0.853	0.868	0.806	0.940
2009	0.736	0.639	0.716	0.851	0.868	0.885	0.820	0.944
2010	0.738	0.644	0.721	0.855	0.894	0.910	0.843	0.953
2011	0.740	0.648	0.724	0.871	0.893	0.905	0.841	0.939
2012	0.743	0.652	0.729	0.877	0.903	0.923	0.845	0.937

Table 5. Changes in total-factor water managerial efficiency (TFWME) in some provinces of China during 2001-2012

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beijing	0.855	0.863	0.871	0.879	0.887	0.880	0.888	0.896	0.898	0.906	0.908	0.946
Guangdong	0.942	0.943	0.944	0.945	0.946	0.948	0.950	0.952	0.954	0.956	0.958	0.960
Guizhou	**0.911**	**0.914**	**0.917**	**0.920**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Hainan	0.771	0.776	0.781	0.786	0.791	0.788	0.793	0.798	0.795	0.800	0.805	0.802
Henan	**0.866**	**0.868**	**0.870**	**0.872**	**0.875**	**0.920**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Ningxia	**0.881**	**0.889**	**0.897**	**0.905**	**0.913**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Shandong	0.722	0.718	0.714	0.710	0.705	0.700	0.695	0.711	0.694	0.689	0.705	0.688
Shanghai	1.000	0.896	1.000	1.000	1.000	0.915	1.000	1.000	0.993	1.000	1.000	1.000
Tianjin	0.788	0.796	0.804	0.812	0.820	0.834	0.842	0.850	0.884	0.892	0.900	0.934

In the evaluation of the TFWME in certain provinces of China (Table 5), Shanghai's TFWME was maintained at or near a value of 1. The TFWME values in Guizhou (2005-2012), Ningxia (2006-2012) and Henan (2007-2012) were close to the TFWME frontier value of 1 while the TFWME values in Beijing, Tianjin and Hainan were less than 1, suggesting that these three provinces were changing from efficient decision making units to inefficient decision making units under the conditions of eliminating the external environmental differences. Therefore, the TFWE values in these provinces likely benefited from good external environments; thus, the regional water managerial efficiency needs to be improved. However, the values observed in the Guizhou (2005-2012), Ningxia (2006-2012) and Henan (2007-2012) regions suggested a change from inefficient decision making units to efficient decision making units in the TFWE evaluation, indicating that these regions had a stronger water resource management ability, though the environmental inefficiency caused by the external environmental disadvantage was more serious.

Because of the relatively large differences in the TFWE and its components in the provinces, effective ways and directions for the improvement of the water efficiency were determined for each province (Table 6). The average TFWME was less than 1 and the

TABLE 6. Strategies for improving the total-factor water efficiency, including the total-factor water managerial efficiency (TFWME) and total-factor water environmental efficiency (TFWEE) in the provinces of China

Province	2001-2012 average		Strategies		Province	2001-2012 average		Strategies	
	TFWME	TFWEE	Improve management	Improve environment		TFWME	TFWEE	Improve management	Improve environment
Anhui	0.695	0.789	△	△	Jiangxi	0.757	0.76	△	△
Beijing	0.89	1.125	△		Jilin	0.614	0.896	△	△
Chongqing	0.735	0.733	△		Liaoning	0.684	0.805	△	△
Fujian	0.824	0.673	△	△	Inner Mongolia	0.722	0.887	△	△
Gansu	0.781	0.846	△	△	Ningxia	0.957	0.67		△
Guangdong	0.95	0.706		△	Qinghai	0.815	0.823	△	△
Guangxi	0.773	0.807	△	△	Shandong	0.704	0.886	△	△
Guizhou	0.972	0.684		△	Shanghai	0.984	1.018		
Hainan	0.791	1.265	△		Shaanxi	0.687	0.92	△	△
Hebei	0.721	0.792	△	△	Shanxi	0.71	0.894	△	△
Heilongjiang	0.662	0.819	△	△	Sichuan	0.697	0.836	△	△
Henan	0.939	0.582		△	Tianjin	0.846	1.185	△	
Hubei	0.641	0.832	△	△	Xinjiang	0.78	0.844	△	△
Hunan	0.663	0.869	△	△	Yunnan	0.612	0.812	△	△
Jiangsu	0.878	0.72	△	△	Zhejiang	0.821	0.801	△	△

Note: △ represents the strategy of enhancing total-factor water efficiency.

average TFWEE was greater than 1 in Beijing, Tianjin, Shanghai and Hainan, indicating that their external environments had advantages, but there were water resource managerial inefficiencies to varying degrees. Therefore, these provinces should not ignore their water managerial inefficiency because of the advantage of their external environment and instead pay more attention to improvements in management for enhancing the water efficiency. A total of 21 provinces, including Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Hubei, Hunan, Guangxi, Chongqing, Sichuan, Yunnan, Shaanxi, Gansu, Xinjiang and Jiangxi have both water managerial inefficiencies and environmental inefficiencies and thus should implement strategies for improving both their managerial ability and the external environment. In Guangdong, Guizhou, Henan and Ningxia, the water efficiency was mainly affected by the external environmental disadvantage; therefore, an external environmental optimisation is the most important method for improving the water efficiency.

5.4. **Analysis of the total-factor water resources environmental variables.** As described in the previous section, there were large differences between the TFWE and TFWME because of the significant environmental differences in the regions. If the key environmental influences can be clearly identified, then specific methods for improving the environmental inefficiency and promoting the water efficiency can be implemented. The water efficiency is affected by diversified factors from the external environment, and the diversified factors from a complicated affecting system. This paper intended to study the external environment from the perspectives of industrial structure, technological progress and water price. We used the water input slack variable obtained from the first stage of the four-stage DEA model as a dependent variable and set four environmental factors, including the industrial structure, technical level of industrial wastewater treatment, technological improvement level and water price as the independent variables. In view of the input slack variable from 0 to infinity [32], the Tobit regression model was used to estimate the influence of the environmental factors on the water input slack variable (Table 7).

The research showed that the four environmental variables, namely the industrial structure, openness level, educational level and infrastructure, had significant effects on the water input slack variable. Because of the regression of an environmental variable on the water input slack variable, increasing the environmental variable caused the input waste

Table 7. Results from the Tobit regression model

Variable	Coefficient
Industrial structure	231.552***
	(33.993)
Industrial wastewater treatment capacity	−69.322**
	(13.552)
Technological improvement level	−266.771*
	(101.991)
Water price	−0.076
	(0.018)

Note: the values in brackets are the standard errors; *** indicates a significance level of 1%; ** indicates a significance level of 5%; * indicates a significance level of 10%.

to reduce when the regression coefficient was negative, while increasing the environmental variable when the regression coefficient was positive would lead to more wasted input.

The industrial structure had a significant positive correlation with the water input slack variable, indicating that the water input slack variable would be greater if the secondary industry had a higher proportion. In China, the proportion of the primary industry is generally below 20%, and the secondary industry and the service industry have become the main driving force of economic development. Compared with the service industry, the secondary industry is characterised by high water consumption and the use of redundant water resources, as it is easier to produce the water waste in the water-intensive sectors of the secondary industry. For example, Beijing's TFWME was 0.898 in 2009, while the TFWE reached a value of 1 at the same time. One of the reasons is that its industrial structure has outstanding advantages, and the environmental advantages make up for the inefficient management to a certain extent. Beijing has a developed service industry, and the proportion of the service industry reached 75.5% while the proportion of the secondary industry was only 23.5% in 2009. In Beijing, producer services and the cultural and creative industries are important components of the service industry and respectively account for 49.5% and 12.6% of Beijing's GDP. In 2009, the TFWME was 1 in Guizhou, but the TFWE was only 0.68 at the same time. These results were related to Guizhou's industrial structure. Guizhou is a province with rich water resources but its coal and electric power industries are the main traditional industries. In 2009, the proportion of the secondary industry had increased to 61.5%. With the development of its tourism, Guizhou's TFWE increased to 0.72 in 2012. Therefore, the optimisation and upgrading of the industrial structure could significantly improve the external environment of water resources and have become important ways to improve the water efficiency in regions to result in changes to the model of economic development.

The industrial wastewater treatment capacity had a significant negative correlation with the water input slack variable. The water input was reduced with improvements of the industrial wastewater treatment capacity and the utilisation rate of wastewater. The wastewater treatment rate has increased from 5% in the year 2000 to 25% in 2012 in the provinces of China.[1] Although the wastewater treatment rate has gradually increased, regional wastewater treatment rates have some differences; for example, the wastewater treatment rates in cities in the eastern region such as Shanghai, Zhejiang and Jiangsu are 71.234%, 69.335% and 67.551%, respectively, while the wastewater treatment rates in the central region such as Chongqing and Yunnan are 32.214% and 11.249%, respectively.

The level of industrial technological improvement had a significant negative correlation with the water input slack variable. The average annual growth rate of the technological improvement expense is 15.124% in China. However, provinces such as Beijing, Shanghai, Jiangsu, Zhejiang and Guangdong have greater technological improvement expenses, and their total expenses account for 35.624% of the national expense. Sufficient expenses allow for rapidly upgraded technology in these provinces, which allows the provinces to save water. The central region relies on industrialisation transferred from the eastern region; thus, the technological improvement expense is lower. The northeastern region expense and the growth rate are far lower than that of the eastern region. In the central and northeastern regions, backward production technology and equipment consume more water resources, and the technological improvement is necessary for saving water.

The water price had no significant negative correlation with the water input slack variable. The main reason is that the regions have very low water prices in order to support the industry development and they have not made a significant adjustment, so

[1] According to the data of China Environment Statistical Yearbook

the water prices significantly deviate from the actual prices of the market. In China, only Beijing, Shanghai, Tianjin and Guangdong have adjusted their industrial water prices and the other regions have not had significant adjustments of their industrial water price for a long period of time.

6. **Conclusions.** The evaluation of total-factor water efficiency (TFWE) completed a transformation from the 'partial-factor perspective' to the 'total-factor perspective', but it still is an evaluation of the comprehensive and complex water efficiency and includes both 'managerial factors' and 'environmental factors'. Evaluations using the standard TFWE are unable to identify the roots of water inefficiency. To solve this problem, this paper used the four-stage DEA model as a theoretical tool to further resolve the TFWE into the total-factor water managerial efficiency (TFWME) and total-factor water environmental efficiency (TFWEE) from the two dimensions of environment and management. Subsequently, this study systematically evaluated the TFWE, TFWME and TFWEE in the provinces of China to evaluate the regional water management ability and identify the external environmental influence on the regional water efficiency in order to help find ways and strategies of improving these efficiencies.

The results of this research showed that the TFWE was still at a lower level in China, and the total-factor water managerial and environmental inefficiencies led to the total-factor water inefficiency. The water saving potential was approximately 30% to 40% of the water consumption and improvement of the water efficiency could sufficiently relieve shortages of regional and national water resources. A rising trend was observed in the TFWE, but the TFWME declined at the same time indicating that there was a lack of motivation to enhance the internal water managerial efficiency. At this stage, the improvement of the water efficiency mainly depended on improving the external environment. Although the TFWE had a larger difference from the TFWME, the regional data were very similar with the eastern region ranking first, the northeastern region ranking at the bottom, and the western and central regions ranking second and third, respectively. At the same time, the eastern region had the most prominent environmental advantage, and the northeastern, central and western regions had different weaknesses in their environment. The main strategy for improving the TFWE is to improve the 'management' and 'environment', but the different provinces should have different emphases. Beijing, Tianjin, Shanghai and Hainan should focus on improving the ability of the regional water resource management. Guangdong, Guizhou, Henan and Ningxia should focus on optimizing the external environment. Hebei, Shanxi and Jilin should work at both the management and environment. Finally, reducing the proportion of the secondary industry, improving technology and industrial wastewater treatment methods and adjusting the water prices could effectively reduce the water consumption such that the regions with disadvantaged environments have the direction and means to improve the TFWE. Overall, the status quo of China's water efficiency is not optimistic. In view of the above conclusions, the following policies and countermeasures are put forward.

First is the reformation of the evaluation system of economic performance of local governments and active adjustment of the industrial structure. For many years, China has focused on the GDP and the economic growth rate in evaluating regional economic development, but since only the 'quantity' of economic development is emphasised, it is unable to reflect the 'quality' of economic development. This seriously affects the governmental macro-control and the governmental role of making policies for optimizing the industrial structure and the economic growth model. In China's regional economic growth, the constraints of water resources and the environment are increasing, and the evaluation system of the local governments' economic performance should not only pay attention to the regional economic growth in the scale and speed but also reflect the costs of water resources, other resources, and the environment for the regional economic growth to objectively reflect the regional economic growth sustainability. Therefore, improvements in the evaluation system for the 'quality' of the regional economic growth are urgently required. The TFWE should be regarded as one of the evaluation indicators of the quality of regional economic development and clearly included in the evaluation index system of regional economic growth performance. Changing the orientation of the performance evaluation system of local governments will provide a secure system for enhancing the regional water efficiency and allow for further development of the governmental role in the regulation, guidance, support and coordination [33].

The second recommendation is to establish restriction and incentive mechanisms for enhancing water managerial awareness and ability. This may be accomplished through the active improvement of water-saving and waste reduction laws, regulations, and standards, strengthening the responsibility assessment of achieving water-saving and waste reduction targets, perfecting the system of rewards and punishments, saving water in production, circulation, consumption, construction and other fields and accelerating the construction of a resource-saving and environmentally-friendly model of production and consumption to enhance the capacity for sustainable development. Actively implementing a preferential income tax, preferential value-added tax, and other policies of the government supporting water-saving and waste reduction could result in the improvement and implementation of preferential tax policies for the comprehensive utilisation of water resources and renewable water resources development. The leverage function of fiscal policies may encourage the further research and development of water-saving technologies by large enterprises and encourage the promotion of key industrial demonstration projects of water-saving and waste reduction. This will encourage enterprises to import water-saving equipment, accelerate the application of water-saving techniques and products and improve the water-saving capacity, as well as encourage the promotion of domestic and foreign advanced managerial experiences and models and the further enhancement of the quality of water resource management and innovation of the water resource managerial model to improve the water-saving managerial ability. Finally, improving market-oriented water-saving mechanisms by actively promoting the contract system of water resource management and accelerating the introduction of financial support policies will guide professional water-saving services companies to use the contract system of water resource management for water-saving improvements of water consumption units and support the growth of the water-saving services industry.

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