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Impact of Public Service Quality on the Efficiency of the Water Industry: Evidence from 147 Cities in China

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Abstract: Nowadays, water service marketization has become a global trend, and the quality of public services has gradually become an important factor affecting the input and output of urban water utilities. This paper defines the connotation of service quality at the technical and public aspects innovatively, builds on the service quality system of water utilities, establishes the relationship between the quality and output efficiency model, and studies the impact of service quality on the efficiency of water utilities. Then, based on 147 cities' water supply data during the 2005–2016 period in China, the data envelopment analysis model and Tobit panel data model were used in the empirical research to measure the efficiency characterized by the quality dimension. The results show that: (1) The service quality of the water industry is reflected in two aspects: technical and publicity. At the technical level, the service quality of the water industry can be represented by the supply capacity of water and infrastructure, and at the public level, by the penetration rate. (2) The overall comprehensive efficiency of urban water utilities in China is in the middle level of 0.5–0.7, the scale efficiency is at a high level of 0.8–1, and the pure technical efficiency is relatively low. The opportunity cost of maintaining service quality in China's water sector is 5.21% of the potential output. (3) Public service quality is significantly positively correlated with the efficiency of China's water utilities, and the improvement of service quality will promote the improvement of efficiency.

Keywords: the water sector; service quality; efficiency; DEA-Tobit model

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1. Introduction

Water products play a very important role in human development [1]. As a kind of quasi-public goods, water products are different from ordinary goods, and their quality deserves more attention [2,3]. The quality of water products concerns the health and safety of every inhabitant.

In the past decades, China has focused more effort on improving the development efficiency of the water utility industry [4]. Since 1992, China has actively introduced foreign investment into the water industry, and by 2015, the foreign entities had gradually transformed into specialized technology providers [5]. Meanwhile, private capital has been actively guided into the water sector [6]. In recent years, with the gradual improvement of water resources infrastructure construction such as water plants and pipe networks, and the gradual improvement of operation efficiency, the financial losses of the water industry have been improved to some extent [7–9]. Table 1 shows the water-related affairs changes in China.

However, with the acceleration of China's industrialization and urbanization, the increasing urban population is generating a further increase in the demand for the quantity and quality of water products [10,11]. Recently, China has experienced a few water pollution incidents each year, examples include the water pollution incident in Puyang City, Henan Province, arsenic contamination in Yueyang, Hunan Province, and the Taihu Lake Water Pollution Incident in 2007, causing hundreds of thousands of people to be without clean water for months. In addition, the same problems with the quality of water production occur in many countries, such as the lead contamination in Flint, Michigan, the contamination of Cheonggyecheon water in South Korea, and water shortages in Ireland. The occurrence of these events seems to mean that after the construction of the water supply has been improved, water service quality control has become one of the most important links in the process of water operation, and heavily threatens the safety and basic livelihood of urban residents [12,13]. Therefore, studying the quality of water service becomes an indispensable factor to measure the benefits of the water industry, as well as to ensure the effective continuity of urban water services [14–16].

Table 1. The basic situation of urban water supply in China (1991–2016).

Indicator	Unit	1981	1991	2001	2011	2016	AAGR (%)
Water production capacity	Gigaton/day	0.33	1.46	2.29	2.67	3.02	6.34
Total water supply	Gigaton	96.99	408.51	466.1	513.4	580.7	5.1
Length of water supply pipe	Ten thousand km	4.7	10.23	28.93	57.38	75.66	8.02
Annual sewage treatment capacity	Gigaton	-	44.54	119.7	337.6	448.8	16.65
Sewage disposal plant	-	39	87	452	1 588	2 039	11.62
Investment in water supply infrastructure	100 million CNY	4.2	30.2	169.4	431.8	545.8	14.48
Investment in drainage infrastructure	100 million CNY	2	16.1	224.5	770.1	1 222.5	19.51
Proportion of total municipal investment	%	31.79	27.09	16.75	8.63	10.13	−3.23
Per capita daily water consumption	Liter	130.4	196	216	170.9	176.9	0.85
Water popularizing rate	%	53.7	54.8	72.26	97.04	98.42	1.70
Water population	100 million	0.77	1.62	2.58	3.97	4.7	5.15

Source: China Urban Construction Statistical Yearbook.

Based on the above urban water supply service status, this paper uses water supply service quality as the main indicator to measure efficiency and performance and examines the impact of service quality on water supply efficiency under the current water market-oriented reform. Firstly, the current measurement of urban water quality and its relationship with efficiency are reviewed, and the relationship between quality and efficiency is studied with the model. Secondly, a water service quality system is established based on the characteristics of the water industry, and the quality regulation efficiency values are calculated and compared comprehensively with the traditional efficiency indicators. The opportunity cost of maintaining service quality is then calculated. Thirdly, the service quality index system is split, and by establishing a Tobit model, the impact of various specific quality indicators on efficiency is analyzed, and the results of the impact of service quality on efficiency are obtained. Finally, the differences between the main conclusions and previous studies are discussed and some suggestions are given.

This paper makes the following two contributions to the existing literature: first, the scope of this paper includes service quality in China's water market, and the empirical study builds on the context of China's water market reform. So far, scholars have not fully studied this issue [17]. Secondly, the article's innovation is to establish the water industry service quality system using the data envelopment analysis (DEA) model to calculate the quality of output efficiency, prove the significant effect on the quality of the measure of efficiency, and further explore China's water industry in 2005–2016 to maintain the quality of opportunity cost by analyzing the specific impact on the efficiency of service quality.

2. Literature Review

For a long time, through theoretical and practical analysis, some scholars believed that the market-oriented reform of the water industry is a necessary process for the development of public utilities in all countries [18–20]. Research on the impact of marketization on the efficiency of public industries has become a mainstream part of academic research [21]. The research on the service quality of public utilities has also attracted the attention of scholars all over the world [22,23]. The total value of water utility services is an important influencing factor when studying the impact of marketization on the efficiency of the water industry [24–28]. Lin highlights the significance of using service quality as an additional output variable rather than simply as a control variable. According to him, benchmarking is an effective tool to inform urban users about the improvement of infrastructure service levels, and considering service quality in the national water sector regulatory system is more conducive to helping the public understand the efficiency of public services [29]. Molinos argued that service quality among users is an indispensable aspect of performance evaluation in the water industry [30]. The factor of service quality was included in the model to better measure the efficiency when studying the efficiency of the water industry [31]. Moreover, there are some articles that argued that service quality among users is an indispensable aspect of performance evaluation in the water industry [32,33].

In addition, in terms of the service value of water, some scholars believe that the total value of water services should be measured not only by the output, but also by the service quality, which includes the physical and chemical quality of water supply, the supply, and distribution quality of final water products, and so on [34–36]. Based on this view, some studies have incorporated quality indicators into the total value of water services [37–39], such as unaccounted-for water [24], water supply parameters [40], the water loss index [41,42], and the number of complaints [28,35,43]. In addition, some scholars included public welfare indicators measuring water service value [38,44], such as service coverage and continuity [25], maintenance rate [45], quality of drinking water, and wastewater treatment into quality indicators [46], and believe that water service quality should include service value.

There is some controversy about the relationship between water service quality and efficiency. Saal and Parker believed that the improvement of service quality can promote the efficiency of water service [46]. Garcia and Thomas studied the extent of economies of scope in the French water industry and concluded that there are economies of scope in the French water industry, which increase significantly when water loss data is added as an output indicator for analysis [41]. However, some scholars believe that the improvement of quality cannot effectively promote efficiency [37,47,48]. Christopher believed that the improvement of quality requires the corresponding opportunity cost compensation [49], such as the repair and maintenance cost of the pipe network [24] and the cost of public relations [26].

At present, most of the research conclusions on urban water utilities efficiency are the results of efficiency measurements. It is believed that the impact of quality factors on efficiency is uncertain, and most of the relevant research focuses on the impact of market mechanisms and government regulation on water efficiency [50–52]. Although some studies have considered the quality of water supply service, they are all studies on a single indicator or a series of indicators [53,54], and the impact of comprehensive factors of water supply service quality on efficiency has not been studied. Therefore, this paper attempts to construct a water supply service quality system, and then introduces water supply service quality into efficiency analysis to study the impact of water service quality on efficiency.

3. Theoretical Analysis

Because water products are composite products combining water quality and water quantity, the water industry should pay attention to quality while considering the output problem to make the best choice. If only the quantity of output is considered and the quality factor is ignored, the best point of choice might not be reached in the quantity and quality trade-off, resulting in high quantity and too low quality or excessive cost invested in the quality dimension, which leads to the encroachment of resources that could have improved the quantity [25,55]. This notion is graphically represented in Figure 1.

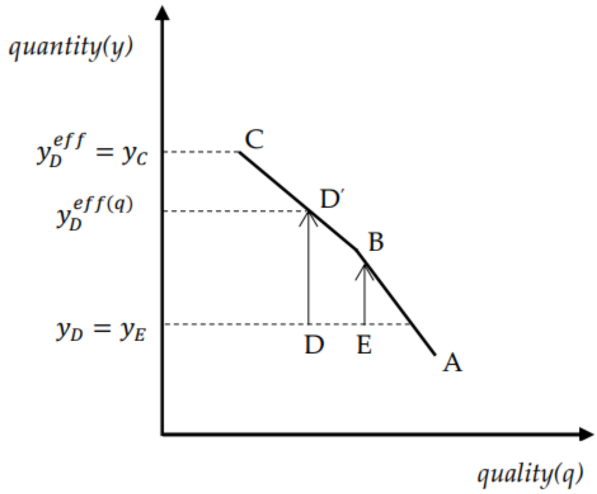

Figure 1. The trade-off between quality and quantity in the water industry.

To simplify the analysis, this research considers five Decision Making Units (DMU) among A, B, C, D, and E and assumes that they use one single input to produce one single output. Y measures the quantity dimension of output, and B measures the quality dimension. Obviously, it can be observed that A, B, and C represent efficient DMUs, while D and E are not efficient DMUs and could have a better output level. The downward part of the broken line represents the trade-off between quality and quantity. Considering DMU D as a subject of analysis, according to the prior quantities, it can be estimated that the potential output efficiency at point D should be $y_D^{eff(q)}$; this effective or potential reference unit is consistent with the production reference DMU C. Without considering the dimension of quality, under the limited input levels, DMU C is the most efficient decision-making unit among the samples and has the largest y_C output quantity. Thus, achieving technical efficiency on the quantitative dimension means a loss of quality (an increase in inferior quality). In contrast, if the quality dimension is considered and the technical efficiency of DMU D is guided by quality adjustment, the maximum output point is D′, instead of C, under the premise of maintaining a certain quality [56,57]. Therefore, D′ is the most efficient unit of reference for D when considering with the quality dimension. Obviously, there are differences between traditional and quality-oriented technical efficiency decisions, and the difference represents the opportunity cost of maintaining quality.

Analyzing the DMU D and E, the two units use the same level of input X to produce the same quantity of Y. Traditional quantity-based efficiency measures, in the output-oriented case, treat the efficiency of both as the same score (in both cases, their baseline effective unit is C), even though they are at different quality levels. In contrast, the quality-adjusted efficiency measurement will give different efficiency scores to D and E, and E will be given a higher efficiency score than D because E is at a better quality level under the same quantity of output. In summary, there is a trade-off between quality and quantity, and there are differences between the quality-adjusted efficiency measurement and the traditional efficiency measurement [35]. Considering the quality factor, the efficiency evaluation will be affected [58].

In the water industry, the relationship between quality and benefit–cost indirectly affects technical efficiency, as measured by the ratio of output to input [59]. In the case of a certain output, the higher the quality, the higher the input, and the lower the efficiency (because, with the improvement of quality, it is necessary to strengthen the maintenance of pipe network infrastructure and water purification to maintain a higher level of quality, and all of these works cost money) [60]. There is also a link between quality and output for the specific water utility industry. High water service quality can ensure the smooth delivery of water products to users, thus reducing the loss of output, and the reverse ensures the increase in output. For example, the high-quality pipe network infrastructure can reduce the leakage rate and ensure an increase in water products [61]. Therefore, as shown in Figure 2, the improvement of service quality will ensure a continuous increase in output quantity, and the relationship between quality and output is positive. When the input is timed, the higher the quality, the lower the output loss, the higher the total output, and the higher the efficiency.

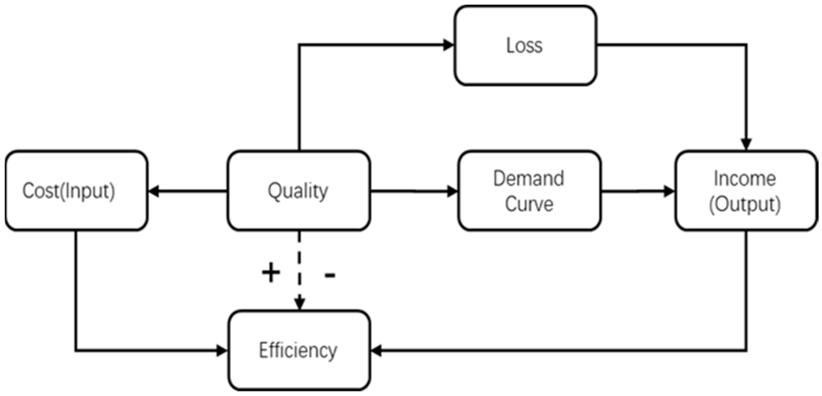

Figure 2. The effect mechanism of quality on efficiency.

In summary, quality has an impact on both output and input, and its impact on efficiency depends on the relationship between marginal quality income and marginal quality cost. When marginal quality income is greater than marginal quality cost, improving quality will promote the improvement of efficiency. In the case that marginal quality income is less than marginal quality cost, the improvement of quality will lead to a decline in efficiency.

On the basis of the above analysis, we consider that water products are necessities of life for residents and have a special attribute that is different from normal commodities—the attribute of being quasi-public goods. The difference in water service quality is mainly reflected in the vertical differentiation of products, and the supply of water products in the vast majority of countries must meet mandatory standards such as the Sanitary Standards for Drinking Water. Therefore, we believe that water service quality should be a comprehensive service quality measured from the direction of supply, mainly measured by objective indicators, rather than subjective quality measured from a consumer perception perspective, rather than subjective quality from the perspective of consumer perception. Water quality and infrastructure quality, such as comprehensive water quality, pipeline leakage rate, and pressure pass rate, should be classified as technical indicators of water service quality and are important factors in assessing water service quality.

Therefore, this paper explores the impact of public service quality on the efficiency of water utilities in China's water market. Through the construction of a water supply service quality system, the influence mechanism between water supply service quality and water supply efficiency is analyzed, and the water service quality is defined and measured. Furthermore, this paper measures the efficiency of China's current water industry [15–17], verifies whether there is a relationship between water service quality and efficiency, and determines how water service quality affects efficiency.

4. Methods

There are many methods to measure efficiency, such as DEA, SFA, and OP-LP. Referring to the studies by Picazo. T. et al. (2008) [24], Kumar. S and Managi. S. (2010) [26], and Romano. G. et al. (2017) [38], this paper used the DEA model to calculate the efficiency of the water industry. DEA is a very important method to evaluate efficiency, which is widely used in various fields, especially in the field of urban water [24,26,56]. Considering that the performance and quality indicators of the water industry in this paper are complex, mainly including multiple input and output indicators, the DEA model is suitable for the efficiency measurement of the multi-input and multi-output models. Moreover, compared with SFA and OP-LP models, The EA method does not need to determine the form of production and cost functions, which simplifies the research process. The specific mathematical model supposes that there are n water enterprises (n decision units). The numbers of types of input and output items of each decision unit are M and P. $X_j = \left(x_{1j}, x_{2j}, \ldots, x_{mj}\right)$ is the input of the No.j water utility, $Y_j = \left(y_{1j}, y_{2j}, \ldots, y_{mj}\right)$ is the output item of the No.j water utility. We use $\left(X_j,\ Y_j\right)$ to denote the DMUj of the No.j water enterprise. $V = (V_1, V_2, \ldots, V_m)^T$, $U = \left(U_1, U_2, \ldots, U_p\right)^T$ represents the corresponding weighting coefficient. By always selecting weights coefficients v and u to make $\frac{u^T Y_j}{v^T X_j} \leq 1,\ j = 1, 2, \ldots, n$, this study constructs the following DEA model (BCC model).

$$\min\left[\theta - \varepsilon\left({e'}^T s^- + e^T s^+\right)\right] \tag{1}$$

$$\text{s.t.} \sum_{j=1}^{n} X_j \varphi_j + S^- = \theta X_0$$

$$\sum_{j=1}^{n} Y_j \varphi_j - S^+ = Y_0$$

$$\varphi_j \geq 0,\ j = 1, \ldots, n$$

$$S^- \geq 0,\ S^+ \geq 0$$

Therein with S^+, S^- as slack variables, ε as the non-Archimedes dimensionless small, and including an extra convexity restriction included on weights: $\sum_1^n \varphi_j = 1$, ${e'}^T = (1, 1, \ldots, 1) \in R^m$, $e^T = (1,\ 1, \ldots 1) \in R^m$, if $\theta^0 = 1$, and S^{-0}, S^{+0} are zero at the same time, then DMU0 can be called an efficiency unit.

In order to verify the influence of the water service quality system on efficiency, a Tobit model was built to study the relationship between the service quality and efficiency of the water industry [62]. Water quality, leakage rate, pipe network pressure qualification rate, penetration rate, and GDP growth rate are selected to represent the service quality indicators of the water industry [63], and the Tobit regression model is established as follows:

$$\text{Model 1}: \ Y_1 = \alpha_0 + \alpha_1 A_{it} + \alpha_2 B_{it} + \alpha_3 C_{it} + \alpha_4 D_{it} + \alpha_5 gdp_{it} + \varepsilon_{it} \tag{2}$$

$$\text{Model 2}: \ Y_2 = \beta_0 + \beta_1 A_{it} + \beta_2 B_{it} + \beta_3 C_{it} + \beta_4 D_{it} + \beta_5 gdp_{it} + \varepsilon_{it} \tag{3}$$

$$\text{Model 3}: \ Y_3 = \gamma_0 + \gamma_1 A_{it} + \gamma_2 B_{it} + \gamma_3 C_{it} + \gamma_4 D_{it} + \gamma_5 gdp_{it} + \varepsilon_{it} \tag{4}$$

wherein α_0, β_0, and γ_0 are intercept terms, A is the comprehensive qualified rate of water quality, B is the leakage rate, C is the qualified rate of pipe network pressure, D is the penetration rate, and GDP is the GDP growth rate. Y_1, Y_2, and Y_3 therein are, respectively, comprehensive efficiency, pure technical efficiency, and scale efficiency. Three models are established in sequence.

This paper uses the relevant data over the period of 2005–2016 from the *Statistical Yearbook of Urban Water Supply* to calculate the efficiency of the water industry. In December 2016, the National Development and Reform Commission (NDRC), and the Ministry of Housing and Urban-Rural Development (MOF) of China issued "the *13th Five-Year national urban sewage treatment and recycling facilities construction plan*" in January 2017, the NDRC, Ministry of Water Resources, and the MOF of China issued "*The 13th Five-Year Plan for Conservation-oriented social Construction*". The implementation of these two policies has a great impact on our calculation of input–output and the measurement of water quality indicators (To ensure the rigor of the empirical results, we did not use data beyond 2016). According to the business characteristics of the water industry and previous studies [21,40,41], the net value of fixed assets is used to measure the asset input variable, and the length of the pipe network and total power consumption are selected as the other two input indicators. Finally, the labor cost factor is considered, and the total wage is selected as the fourth input term. The total water supply output is used as the index to measure the output of the water industry. The population served by water is another indicator of the output of water services.

Furthermore, the research refers to the studies of Picazo et al., Kumar, and Managi [24,36,64] and considers the quality of water and pipeline infrastructure as well as the quasi-public-good nature of the water industry. Therefore, we summarized the constructed index system into two main aspects and constructed a service quality system to measure the service quality of water products from two aspects, three dimensions, and four indicators at the technical level and the public level, which were less considered in previous studies.

The water service quality system is established at three levels. The service coverage rate is used to measure the quasi-public-product attribute of the water products. The comprehensive qualified rate of water quality is used to measure water quality. The quality of pipe network infrastructure is measured using the leakage rate and the qualified rate of pipe network pressure. The penetration rate is applied to measure the service coverage rate, which is the ratio of the total urban population water served to the total urban population. As the main index of publicity, the penetration rate has become the main basis for measuring the service scope of public goods and quasi-public goods [17,39,46] and should be the main index for measuring water quality. Meanwhile, it is usually only used as a macro indicator of the water industry in previous studies on water services, and rarely included in the index system of water service [22,47]. Specific indicators of the water service quality system are shown in Table 2.

Table 2. Water service quality system.

Water Service Quality System		Measurement Index
Technical aspect	Water quality	Comprehensive qualified rate of water quality
	Quality of pipe network infrastructure	Leakage rate Pipeline network pressure pass rate
Publicity aspect	Service coverage rate	Popularizing rate

Note: pipeline network pressure pass rate = $\frac{\text{Number of qualified pipeline network pressure}}{\text{Total number of pipeline network pressures}} \times \%$, in the *China Urban Water Supply Statistical Yearbook*.

Because all of the indicators of the water utilities service quality system are proportional numbers, in accordance with the rules of geometric quotas, the average of the four variables in the water service quality system is calculated. When the quality of the leakage rate is negative, we retrieve the gap value between 1 and the leakage rate for calculation, and the comprehensive index value of water utilities service quality is obtained as a factor to measure water utility service quality [63]. At the same time, in order to unify index values of output items, the total water supply, and the population served in water are standardized, and the deviation standardization method is applied to lock the values within the range of 0 to 1. See Table 3 for specific input–output indicators.

The three efficiency values measured by the DEA model are then applied as explanatory variables, and the water service quality system is taken as an explanatory variable to establish the Tobit model. Table 4 shows the selection of specific indicators. The descriptive statistics of the data used in the Tobit model are shown in Table 5.

Table 3. Quality-adjusted input–output indicators.

	Indicator	Unit
Input term	Net fixed assets The total wages The total power consumption Pipe length	Ten thousand CNY Ten thousand CNY Ten thousand kilowatt · hour Km
Output term	The total water supply Population served water	Gigaton Ten thousand people

Table 4. Selection of regression variables.

	Indicator
Explanatory variables	Comprehensive qualified rate of water quality Leakage rate Pipeline network pressure pass rate Popularizing rate
Control variables	The GDP growth rate
Explained variable	Three DEA efficiency measurements

Note: The data are from the *Urban Water Supply Statistical Yearbook* and the website of the National Bureau of Statistics.

Table 5. Descriptive statistics of the variables.

Variable	n	Ave	Std.	Max.	Min.
Comprehensive efficiency	1764	0.643	0.201	1	0.171
Pure technical efficiency	1764	0.747	0.204	1	0.175
Scale efficiency	1764	0.865	0.137	1	0.292
Comprehensive qualified rate of water quality	1764	0.997	0.007	1	0.899
Leakage rate	1764	0.215	0.106	0.875	0.0145
Pipeline network pressure pass rate	1764	0.988	0.029	1	0.6
Popularizing rate	1764	0.917	0.125	1	0.325
The GDP growth rate	1764	0.109	0.026	1	−0.025

5. Results

Based on the data from the Statistical Yearbook of Urban Water Supply from 2005 to 2016, according to the selected input–output indicators, 147 cities with relatively complete data are selected as research samples, and the DEAP 2.1 software is used to calculate their efficiency values over a period of 12 years.

5.1. Water Market Efficiency

According to DEA calculation results, three kinds of efficiency values for 147 cities from 2005 to 2016 are obtained. Tables 6 and 7 describe the average efficiency values and minimum values of all samples during each year.

As can be seen from the tables above, the value of comprehensive efficiency exhibits a fluctuating form. From 2005 to 2016, the average level of the three efficiency values measured by DEA can all reach above 0.5, and there is no obvious trend of continuous rise or decline in the past 12 years, but instead a long-term fluctuation. It indicates that the efficiency value of the water industry will fluctuate during different years, but there is no overall sustained trend, indicating that China's water industry is in long-term steady development. Comprehensive efficiency values range from 0.5 to 0.75. The scale efficiency value is larger than that of pure technical efficiency, and the value range is mostly between 0.8 and 1. The higher value range indicates that the scale efficiency of the current water industry is at a higher level. The value of pure technical efficiency is mainly in the range of 0.6 to 0.8, indicating room for improvement in the pure technical efficiency of the water industry.

Table 6. Average efficiency.

Year	Comprehensive Efficiency	Pure Technical Efficiency	Scale Efficiency
2005	0.557	0.653	0.878
2006	0.641	0.721	0.889
2007	0.676	0.763	0.890
2008	0.623	0.750	0.830
2009	0.683	0.785	0.873
2010	0.653	0.771	0.848
2011	0.674	0.792	0.856
2012	0.686	0.781	0.883
2013	0.585	0.730	0.809
2014	0.613	0.705	0.871
2015	0.628	0.695	0.915
2016	0.596	0.723	0.825

Note: All figures in the table are reserved to three decimal places.

Table 7. Efficiency minima.

Year	Comprehensive Efficiency	Pure Technical Efficiency	Scale Efficiency
2005	0.171	0.175	0.292
2006	0.317	0.355	0.560
2007	0.312	0.349	0.544
2008	0.183	0.358	0.463
2009	0.301	0.407	0.444
2010	0.205	0.271	0.336
2011	0.319	0.403	0.468
2012	0.297	0.357	0.413
2013	0.239	0.261	0.368
2014	0.233	0.281	0.502
2015	0.210	0.219	0.423
2016	0.187	0.243	0.480

Note: All figures in the table are reserved to three decimal places.

In terms of minimum values, the efficiency values for 2005, 2010, and 2013 are all low. The average efficiency values took a hit in 2005 and 2013, which are relatively low-value years. However, the average value in 2010 is good. Therefore, it is determined that there are large differences in the efficiency values among regions during this year. There are regions with low efficiency and regions with high efficiency values. In the three years from 2014 to 2016, the minimum value of scale efficiency is about 0.5, which indicates that, since 2014, the scale efficiency of water utilities in most regions of China is relatively high, and there is no extremely low phenomenon. The generally high value of scale efficiency also drives the improvement of comprehensive efficiency.

5.2. Quality-Adjusted Water Utilities Market Efficiency

After considering the inclusion of quality indicators, this paper used DEAP 2.1 software to calculate the new data and obtain the quality-adjusted estimated value of the DEA efficiency of the water industry. Table 8 describes the comparison of the annual average efficiency value between the traditional DEA and the DEA measurement method with the addition of quality adjustment.

Table 8. Comparison of two DEA efficiency values.

Year	Traditional DEA Efficiency Value	Quality-Adjusted DEA Efficiency Value	Opportunity Cost of Maintaining Quality
2005	0.557	0.645	8.80%
2006	0.741	0.793	5.20%
2007	0.676	0.725	4.90%
2008	0.623	0.685	6.20%
2009	0.683	0.726	4.30%
2010	0.653	0.710	5.70%
2011	0.674	0.732	5.80%
2012	0.686	0.726	4.00%
2013	0.585	0.641	5.60%
2014	0.613	0.653	4.00%
2015	0.628	0.655	2.70%
2016	0.596	0.649	5.30%
Mean value	0.635	0.695	5.21%

Based on these charts, it is clear that in all years from 2005 to 2016, the quality-adjusted DEA efficiency value is slightly higher than the traditional DEA efficiency value; the average value of 12 years of traditional DEA efficiency measurement is 0.635, indicating 147 samples in the case of a given input can produce quantities equaling 63.5% of potential outputs on average. The potential output is also called the output efficiency, representing the most efficient output under the given input. The DEA efficiency with the addition of quality adjustments averages 0.695 over the 12-year period, indicating that, on average from 2005 to 2016, most regions achieved an output level of 69.5% of potential output. From the perspective of potential output loss, the difference between the efficiency values measured by the two methods represents the opportunity cost of maintaining the quality of water services. Therefore, according to the data in Table 6, the average opportunity cost of maintaining service quality in China's water industry in 12 years is 5.21% of the efficiency output.

In order to further verify the validity of our results, the F test, Wilcoxon rank sum test, and Spearman rank correlation test are carried out on the quality-adjusted DEA efficiency value and the traditional DEA efficiency value data year by year, respectively, to explore whether quality affects the measurement of the traditional DEA efficiency [3,30]. Table 9 shows the test results.

Table 9. Results of significance difference test.

Year	F Test	The Wilcoxon Rank Sum Test	The Spearman Rank Correlation Test
2005	12.923 ***	−3.413 ***	0.773 ***
2006	6.407 ***	−2.58 ***	0.905 ***
2007	5.431 **	−2.431 **	0.908 ***
2008	7.046 ***	−2.811 ***	0.950 ***
2009	3.830 **	−2.015 **	0.958 ***
2010	5.705 **	−2.446 **	0.912 ***
2011	7.515 ***	−2.709 ***	0.945 ***
2012	3.421 *	−1.879 ***	0.952 ***
2013	5.694 **	−2.356 **	0.928 ***
2014	2.601 *	−1.583 *	0.957 ***
2015	1.312	−1.205	0.935 ***
2016	4.656 **	−2.217 **	0.953 ***

Note: *, **, and *** represent 10%, 5%, and 1% test levels, respectively.

According to the test results, all years except 2015 pass the F test, and most of the years pass the F test at the 5% and 1% levels, indicating significant differences between the two groups of data. Similarly, all years except 2015 pass the Wilcoxon rank sum test, indicating that the distribution of the two sets of data differs. The test results show that service quality has an impact on DEA efficiency measurement, and there is a significant difference between the DEA efficiency value of quality adjustment and the traditional DEA efficiency value. According to the Spearman rank correlation test results, all years pass the test at the 1% level, indicating that the two sets of data are not completely independent. Although the DEA efficiency of traditional DEA and quality adjustment is different in mean and distribution, the region rankings in these two cases are not statistically different from each other. Thus, service quality does have an impact on the estimated value of water industry efficiency, but it has little impact on the individual efficiency ranking.

5.3. Influence of Service Quality on the Efficiency of the Water Industry

Using Stata14 software, the Tobit model is used to conduct regression analysis on the water utility data of 147 regions spanning 12 years from 2005 to 2016 to verify the correlation between service quality and water utilities efficiency. The regression results are shown in Table 10.

Table 10. The Tobit model regression results.

Explanatory Variables	Model 1 (Y1)	Model 2 (Y2)	Model 3 (Y3)
Comprehensive qualified rate of water quality (A)	1.4806 ** (0.031)	1.0869 ** (0.048)	0.8846 * (0.082)
Leakage rate (B)	−0.03470 * (0.089)	−0.0294 * (0.068)	0.0058 (0.301)
Pipeline network pressure pass rate (C)	0.3853 ** (0.039)	0.3641 * (0.079)	0.1559 (0.255)
Popularizing rate (D)	0.0412 (0.424)	0.1463 *** (0.010)	−0.1072 *** (0.004)
GDP growth rate (GDP)	0.6537 *** (0.000)	0.7378 *** (0.000)	0.2264 (0.661)

Note: *, **, and *** represent 10%, 5%, and 1% test levels, respectively.

The comprehensive qualified rate of water quality has a positive correlation with comprehensive efficiency, pure technical efficiency, and scale efficiency. By observing the regression results of the effects of the comprehensive qualified rate of water quality on the three efficiencies, it can be found that Models 1, 2, and 3 all pass the significance test, and the estimated coefficients are all positive. Model 3 passes the significance test at the 10% level, while Models 1 and 2 pass the significance test at the 5% level. The regression results show that the comprehensive qualified rate of water quality is positively correlated with comprehensive efficiency, pure technical efficiency, and scale efficiency, and the higher the comprehensive qualified rate of water quality, the higher the comprehensive efficiency, pure technical efficiency, and scale efficiency.

The leakage rate is negatively correlated with comprehensive efficiency and pure technical efficiency. By observing the regression results of the effects of leakage rate on the three efficiencies, it can be found that Models 1 and 2 passed the significance test at the 10% level, and the estimated coefficients were all negative. Model 3 did not pass the significance test. The regression results show that the leakage rate has a negative correlation with comprehensive efficiency and pure technical efficiency. The lower the leakage rate, the higher the comprehensive qualified rate and the pure technical efficiency.

The qualified rate of pipe network pressure demonstrates a positive correlation with comprehensive efficiency and pure technical efficiency. By observing the regression results of the influence of pipe network pressure pass rate on the three efficiencies, it can be found that both Models 1 and 2 passed the significance test. Model 1 passed the significance test at the 5% level, Model 2 passed the significance test at the 10% level, and the estimated coefficient symbols are all positive. Model 3 does not pass the significance test. The regression results show that the qualified rate of pipe network pressure has a positive correlation with comprehensive efficiency and pure technical efficiency. The higher the qualified rate of pipe network pressure, the higher the comprehensive efficiency and pure technical efficiency.

There is a positive correlation between the penetration rate and pure technical efficiency and a negative correlation between the penetration rate and scale efficiency. By observing the regression results of the influence of the penetration rate on the three efficiencies, it can be found that Models 2 and 3 pass the significance test at the 1% level, and the estimated coefficient sign of Model 2 is positive, while that of Model 3 is negative. The regression results show that the penetration rate is positively correlated with pure technical efficiency and negatively correlated with scale efficiency, indicating that the higher the penetration rate, the higher the pure technical efficiency is and the lower the scale efficiency is.

The control variables are positively correlated with comprehensive efficiency and pure technical efficiency. By observing the regression results of the impact of the GDP growth rate on the three efficiencies, it can be found that Models 1 and 2 pass the significance test at the 1% level, and the estimated coefficients are both positive, while Model 3 does not pass the significance test. The regression results indicate that the GDP growth rate is positively correlated with comprehensive efficiency and pure technical efficiency, indicating that the faster the GDP growth rate, the higher the comprehensive efficiency and pure technical efficiency.

6. Discussion

This study focuses on water service quality as the starting point, examines the construction of the water service quality system, increases efficiency by introducing quality factors, and discusses the impact of service quality on water efficiency.

In the studies on the efficiency of the water industry, most scholars take the water supply or main business income as the main index of output to measure the efficiency, and few take the service quality into the output of the water industry to measure the efficiency [39,46,55]. The relationship between quality, quantity, and efficiency is helpful to study the trade-off relationship between quality and quantity and find the optimal choice of quality and quantity [24,26]. This paper takes the water service quality as the focus of studying the efficiency of the water industry and considers the service quality in the efficiency measurement, which can more comprehensively and accurately reflect the real level of the efficiency of China's water industry. The water service quality index system was divided into two topics. From the three dimensions of the two topics, the research results can provide constructive suggestions for effectively improving the efficiency of the water industry, and helps to find the optimal level of quality [65].

From the above study, this paper observes that the quality of water supplies has an impact on both the cost and output of water supplies, so there is extensive debate on the final impact results [19,49,50,59]. Analysis of the regression results reveals that the improvement of the comprehensive qualified rate of water quality has a greater impact on output. With the improvement of the comprehensive qualified rate of water quality, it is necessary to further increase the cost of filtration, purification, and monitoring of water products to maintain a high quality of water products, but the cost of substandard water quality will be greater than the input cost. Therefore, a high comprehensive qualified rate of water quality means less quantity of abandoned water products, thus improving the efficiency of the transportation of water products to users [41,42].

Reducing the leakage rate requires maintenance costs to ensure the normal operation of the pipeline network infrastructure, and reducing the leakage rate can also improve the efficiency of the delivery of water products and reduce the loss of water products. The regression results show that a decrease in the leakage rate can help to improve the comprehensive efficiency and pure technical efficiency of the water industry. There is no significant relationship between leakage rate and scale efficiency. This is contrary to Tynan's research [50].

The high comprehensive qualified rate of pipe network requires great investment; thus, in order to meet the national standard of pipe network pressure qualified rate, one must spend substantial resources to maintain it. However, if the qualified rate of pipe network pressure does not meet the standard, the life and work of users as well as the output of the water supply might be affected [66,67]. As the water penetration rate increases, so does the quantity supplied and sold, and so does output. Although the increase in the penetration rate will drive the construction of related pipe network infrastructure and increase the cost input, the main network can share more infrastructure costs, save unit costs, and improve pure technical efficiency [51]. According to the regression results, the penetration rate is negatively correlated with the scale efficiency, which proves that the higher the penetration rate, the lower the scale efficiency. The excessive scale will increase the complexity of management and increase the cost of management and operation. To a certain extent, this verified the conclusions of Molinos et al. [32].

With the continuous development of China's economy, the continuous increase in urban population, and the continuous improvement of residents' living standards, the demand for water and the requirements for service quality have gradually increased [68]. Water pollution regulation, water industry service quality, and other issues need to be further enhanced [53], this problem not only appears in China but also exists in all countries [67]. According to the result, the improvement of water service quality could enhance the water industry and promotes efficiency, marginal quality benefits outweigh marginal quality costs, and the benefits of quality improvement outweigh the disadvantages. Therefore, this paper proposes the following suggestions: first, strengthen the quality management and monitoring of water products to ensure that the water quality is up to standard, and maintain the comprehensive qualified rate of water quality at a high standard, so as to reduce the loss caused by the substandard quality of water products. Second, it is necessary to further strictly control the maintenance of infrastructure, such as through the supervision of pipe networks and related technical indicators [36,69], to ensure that the water demand of the vast number of users is met. Third, attention should be paid to improving the efficiency of capital use and not blindly investing too much money in maintaining the pipe network infrastructure because there is no obvious relationship between the qualified rate of pipe network pressure and scale efficiency [70]. The water industry cannot expand its scale without limit but should control the scale of expansion within a reasonable range and focus on improving management efficiency.

This paper takes the water service quality as the focus of studying the efficiency of the water industry and considers the service quality in the efficiency measurement, which can more comprehensively and accurately reflect the real level of the efficiency of China's water industry. On the one hand, the research results of this paper are useful for policymakers and public utility management. From a societal perspective, this research can better understand the costs of maintaining quality and the nature of the trade-off between quantity and quality and should help improve the management of utilities. On the other hand, the research results of this paper provide a certain basis for the development direction of the urban water industry. The water supply department should control the maintenance capital input of the water pipe network and apply more funds to improve the water quality and save costs.

7. Conclusions

From the perspective of water service quality, this paper defines the connotation of service quality at the technical and public aspects, builds on the service quality system of water utilities, establishes the relationship between the quality and output efficiency model, and uses data envelopment analysis model and Tobit panel data model to measure the influence of the water industry quality on efficiency using the research findings. The following conclusions are obtained.

(1) The pure technical efficiency of China's water industry is not high enough. In the past ten years, the efficiency of the water industry fluctuated greatly, ranging from

0.5 to 0.7. However, the scale efficiency of the water industry is good, close to the optimal scale situation. The pure technical efficiency falls between 0.6 and 0.8, which indicates great room for improvement. Therefore, it is suggested to strengthen the quality management and monitoring of water quality products to ensure that the water quality meets the standard.

(2) Quality will have an impact on the efficiency of the water industry. There are significant differences between the quality-adjusted DEA efficiency results with the addition of comprehensive quality indicators into output items and the traditional DEA efficiency results. Quality factors have an important influence on water supply efficiency measurement, the water product is a compound product of quantity and quality, and quality factors must be considered in efficiency measurement. Only by adding the efficiency measurement results after quality adjustment can the efficiency of the water industry be evaluated more accurately and comprehensively. It is proposed to strengthen the integrity of water purification and testing links, ensure that water quality can meet national standards, and pay attention to water quality management, to ensure the safety of the water supply.

(3) The cost of maintaining water service quality is high. It is found that maintaining water service quality will result in significant output loss. By calculating the difference between traditional DEA efficiency value and quality-adjusted DEA efficiency value, it can be seen that the average opportunity cost of maintaining service quality in China's water industry during 2005–2016 is 5.21% of the potential output, which reflects the cost that China's water industry has invested in service quality in the past ten years. Therefore, the management scheme of water facilities should be planned in advance to control the maintenance cost of infrastructure, so that the basic demand for water can be better met.

(4) The improvement of service quality will promote the improvement of efficiency in the water industry. The higher the water quality comprehensive rational rate, the pipe network pressure qualified rate, and the GDP growth rate, the higher the comprehensive efficiency. China's water industry is at a stage where marginal quality benefits outweigh marginal quality costs and quality improvement benefits outweigh disadvantages. Policymakers should pay attention to the utilization rate of funds and not blindly invest too much money in the maintenance of pipe network infrastructure. At the same time, the scale of water input should be controlled within a reasonable range, and attention should be paid to improving management efficiency.

There are three limitations to our work. First of all, due to the lack of sample data, only 147 cities out of 334 are selected as samples, and most of the sample cities are located in the economically developed eastern regions of China, while the central and western regions have fewer samples, so there might be a certain degree of sample bias. Secondly, due to the limitation of the length of the article, the robustness test part of the article is not concluded in the text. The choice of quality indicators is based on previous studies and the situation of China's water, but a certain degree of subjectivity is inevitable, to which researchers can devote further research in the future.

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