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Research on the impact of environmental regulation on water resources utilization efficiency in China based on the SYS-GMM model

X. B. Wang and Z. L. Wang

ABSTRACT

The paper uses the super-efficiency data envelopment analysis (DEA) model to measure the water resources utilization efficiency of 30 provinces in China, and then uses the system generalized method of moments (GMM) model to analyze the impact of environmental regulations on China's regional water resources utilization efficiency. Conclusions as follows: (1) The overall water utilization efficiency is low, and the regions are very unbalanced. The more efficient areas are concentrated in the east, and the less efficient areas are in the west; (2) There is a 'U'-shaped relationship between the intensity of environmental regulation and water resource utilization efficiency, that is, weaker environmental regulation intensity is not conducive to the improvement of water resource utilization efficiency, but when the intensity of environmental regulation crosses the 'inflection point', it can promote the improvement of water resources utilization efficiency; (3) The level of economic development has a very significant positive effect on water resources utilization efficiency, and the coefficient of scientific and technological progress is positive, but the impact of scientific and technological input on water resources utilization efficiency is limited and not significant; industrial structure and water resource utilization efficiency shows a negative correlation; water use structure and water resources efficiency show a negative correlation.

Key words | environmental regulation, system GMM, water resources utilization efficiency

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HIGHLIGHTS

- Measure the efficiency of water resources based on super-efficiency DEA.
- Use SYS-GMM to verify the impact of environmental regulations on water resources efficiency.
- Obtain recommendations that help improve water efficiency.

INTRODUCTION

Water resources are an important element of the natural ecosystem, the foundation of human survival and social production, the country's strategic economic resources, and an important part of the overall national strength (Xiao *et al.* 2020; Zhang *et al.* 2020a, 2020b). The contradiction between the supply and demand of water resources in China has become increasingly severe. Extensive economic growth and water pollution have led to serious shortages in water resources in many regions, and have become a bottleneck restricting the coordination and sustainable development of the economy, society, and the ecological environment. China must change its water resources utilization model as

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soon as possible (Pan *et al.* 2020; Wang 2020). System governance models such as 'income and reduce expenditure', 'scientific water saving', and 'effective supply and demand management' should be put on the agenda. Water resource efficiency is the ability to minimize the input of water resources under output while considering the ecological and economic value functions of water resources. Therefore, improving water resources efficiency is a way to alleviate and solve water shortages and promote high-quality economic development (Ding *et al.* 2018). Since the reform and opening up, the Chinese industrial economy has secured world-renowned achievements and has become the world's second largest industrial manufacturing country. However, at the same time, some industries are still stuck in a stage of high pollution, high consumption, and low efficiency, which has resulted in great damage to the Chinese water ecological environment. Since the beginning of the 21st century, China's industrialization and urbanization have gradually accelerated, industry has gradually taken a leading role in Chinese industrial structure, industrial enterprises' demand for water resources has been increasing, and the discharge of various major pollutants in industrial wastewater has been high. The constant situation has led to the continuous deterioration of the water environment (Sun *et al.* 2020; Zhu *et al.* 2020). This poses a threat to the sustainable use of water resources in China. Therefore, under the concept of environmental regulation, it is necessary to strictly regulate the development and utilization of various water subjects, limit the discharge of polluted water resources and strengthen water environmental protection, and ensure that water resources meet domestic and production water. In relation to the water quantity and water quality requirements of ecological water use, improving water resource utilization efficiency is the fundamental way to achieve the above-mentioned daily standards. The efficiency of water resource utilization under environmental regulations can be used to diagnose the problems in the development and utilization of water resources by characterizing the relationship between water resources input, economic output and pollution emissions, to provide a basis for water resources environmental regulations (Graymore & Wallis 2010). Therefore, during the '14th Five-Year Plan' period, the rational use of environmental regulatory tools, efforts to resolve the contradiction between economic development and water resources and the improvement of water resources comprehensive utilization efficiency have become important measures to promote green and coordinated industrial development (Xing *et al.* 2020; Zhang *et al.* 2020a, 2020b).

The main innovations and contributions of this paper are: (1) Uses the input-output ratio and efficiency evaluation index system, and considers the data envelopment analysis (DEA) of undesired output to analyze the water use efficiency of different regions in China; (2) Compares the difference in water use efficiency between China's overall and different regions, and provides theoretical reference for policy exploration; (3) Focuses on the analysis of the impact of environmental regulations on China's water use efficiency, and puts forward countermeasures and suggestions based on this, which can be useful for China to achieve The goal of sustainable development has important practical significance.

LITERATURE REVIEW

The measurement of water resources utilization efficiency

The research on water resource utilization efficiency measurement methods mainly focuses on the application of SFA and DEA. In the application of the SFA method, Gai *et al.* (2014) used the SFA method to measure the urban water use efficiency of Liaoning Province from 2004 to 2013, and analyzed its dynamic evolution trend; Shinji *et al.* (2004) found agricultural production value is regarded as the desired output, and the agricultural water use efficiency of various provinces in China is measured using the stochastic frontier analysis method. Zhang *et al.* (2017) used undesirable output into account when measuring the utilization efficiency of industrial water resources in 30 provinces in China, and used a combination of stochastic frontier analysis and amplitude adjustment methods to obtain industrial green water efficiency. Chang *et al.* (2020) used the SFA method to analyze the annual industrial water efficiency of each province based on the panel data of 31 provinces in China from 2002 to 2013, and formulated the improvement of water resources according to the gap

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between east, central and west and used efficiency measures. Foreign research focuses on the technical and economic efficiency of the water supply sector. Carvalho & Marques (2015) used Bayesian stochastic frontier analysis to estimate the scale and economic efficiency of the Portuguese water sector, and verified the use of Bayesian Method to construct the advantages of stochastic frontier function; Lampe & Hilgers (2015) used literature analysis to review the application of SFA method in performance evaluation, and believed that for efficiency evaluation problems in different fields, DEA and SFA are two methods that are applicable respectively for different situations.

In the application of the DEA method, Lei *et al.* (2017) used the super-efficiency slack variable (SBM) model to explore the temporal changes and spatial distribution of the comprehensive efficiency, pure technical efficiency and scale efficiency of China's grain water use efficiency from 2008 to 2017, and use the Tobit model to analyze the impact of natural environment and production irrigation measures on water efficiency; Liang *et al.* (2017) evaluated the water use efficiency of Hunan Province, and suggestions were made for improving the water resource utilization efficiency; Liu & Yan (2016) used the super-efficiency SBM model in the DEA method to analyze the water use efficiency of 12 western provinces and cities; Ma *et al.* (2012) selected an input-oriented SBM model to analyze the water use efficiency of 30 provinces and cities in the country considering the undesirable output of water resources; Sun *et al.* (2016) measured the utilization efficiency of water resources.

In the application of other methods, Wang & Gong (2017) used the network BAM model to measure the efficiency of urban water resources systems in 29 provinces, municipalities, and autonomous regions in China; Wang *et al.* (2017a, 2017b) considered industrial water and water pollution discharge, adopted the EBM model compatible with radial and non-radial characteristics to measure the Yangtze River economy efficiency of industrial green water resources in Belt 11 provinces and cities; Cao (2017) chooses per capita water consumption and water intensity to measure water efficiency, and uses inter-provincial panel data to study the relationship between China's urbanization and per capita water consumption intensity spatial Kuznets curve; Zhang (2017) used the IPAT model to calculate the critical value of the rate of change of water consumption under the gross domestic product (GDP) growth rate of Shaanxi Province from 2006 to 2015; Deng (2020) took into account the sewage discharge in the process of water resource utilization, adopted the ML index to measure the water resource utilization efficiency of cities across the country.

From the above analysis, it can be seen that domestic and foreign scholars have adopted many methods based on different perspectives when measuring water resources utilization efficiency. Among them, the most widely used methods are DEA and SFA. Both of these methods are from the perspective of input and output. They analyzed the effective utilization of resources, but these are applicable to different efficiency measurement situations. It is necessary to select a suitable efficiency measurement model according to the actual research problem. SFA is widely used in multi-input and single-output problems. DEA is suitable for multi-input and multi-output problems. When considering the unexpected output of water resources utilization, the advantages of the DEA model are more obvious.

Impact of environmental regulations on water resources utilization efficiency

Yang & Liu (2015) applied the Bootstrap regression model to conduct empirical research on the influencing factors of agricultural water efficiency under pollution discharge. Xu & Pan (2019) studied the nonlinear impact of environmental regulations on the efficiency of green water resources. The research found that the three types of environmental regulations affect green water threshold effect of resource efficiency and is spatially heterogeneous, and the threshold value of command-based environmental regulation is lower than the other two types, but market-based environmental regulation has the greatest positive effect on the efficiency of green water resources. Feng *et al.* (2017) found that the industrial water use efficiency in Shaanxi Province is low. Government environmental regulations have a positive effect on the efficiency of industrial water use; Ding *et al.* (2019) showed that water use efficiency and the environment regulations, water use efficiency and FDI agglomeration show significant spatial correlation in most years; Zhang *et al.* (2019) found that

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green efficiency of provincial industrial water resources plays a promoting role, while environmental regulations play a restraining role.

The existing research results have laid the foundation for this article, but there are still some shortcomings: First, less attention is paid to the impact of environmental regulations on water resources efficiency. Second, insufficient consideration has been given to the calculation of water resources utilization efficiency and its influencing factors. This article attempts to improve from the following three aspects: First, based on the connotation of green development, the improved SE-SBM model is used to calculate the water use efficiency value of 30 provinces in China from 2000 to 2017, and measure and analyze the efficiency of green water resources. In addition, reflect the overall picture of water resources efficiency in the country and in various regions. Second, to use provincial panel data to verify the impact of environmental regulations on the efficiency of water resources utilization at the national and regional levels.

METHOD

DEA model

In 1978, Charnes, Cooper, and Rhodes (CCR), three scholars, built an efficiency evaluation model – CCR model. The CCR model is the first model for DEA. The others are based on CCR improvements. Therefore, CCR plays a very important role in the development of DEA. The role of the specific model of the CCR model is as follows: Suppose that it is necessary to measure the water resource utilization efficiency of n decision making units (DMU), and the input and output of each indicator are respectively $X_1 = (X_{11}, X_{12}, X_{13}, \cdots, X_{m1})$, $Y_1 = (Y_{11}, Y_{12}, Y_{13}, \cdots, Y_{k1})$, where inputs include m kinds of inputs, and outputs include k kinds of outputs; supposing these m kinds of inputs and k kinds of outputs. The corresponding weight coefficient vector is $v = (v_1, v_2, v_3 \cdots v_m)^T, u = (u_1, u_2, u_3 \cdots u_k)^T$, by choosing an appropriate v_r, u_s can satisfy $h_i \leq 1$, and the larger the h_i means the higher the efficiency, the greater the output can be obtained with less input. Therefore, the efficiency evaluation index of iDMU is:

$$\begin{cases} max \dfrac{\sum_{s=1}^{k} u_s y_{si}}{\sum_{r=1}^{m} v_r x_{ri}} \\ \dfrac{\sum_{s=1}^{k} u_s y_{si}}{\sum_{r=1}^{m} v_r x_{ri}} \leq 1 \\ v_r \geq 0, r = 1, 2, 3, \cdots m; u_s \geq 0, s = 1, 2, 3, \cdots, k \end{cases} \quad (1)$$

Step 1: Let $t = \dfrac{1}{v^T x_0}, \omega = tv, \mu = tu$, Then perform the Charnes–Cooper transformation on the above formula, and then get the formula (2), as follows:

$$\begin{cases} max \mu^T Y_0 \\ \omega^T X_i - \mu^T Y_i \geq 0 \\ \omega^T X_0 = 1; \omega \geq 0; \mu \geq 0 \end{cases} \quad (2)$$

Step 2: According to the linear programming duality theory, by transforming the model, the model can be transformed into the following form:

$$\begin{cases} min h_i = \theta \\ \sum_{i=1}^{n} \lambda_i X_{si} + S^- = \theta X_0 \\ \sum_{i=1}^{n} \lambda_i Y_{ri} - S^+ = Y_0 \\ \lambda_i \geq 0, S^+, S^- \geq 0 \end{cases} \quad (3)$$

In the above formula, S^- and S^+ are slack variables, indicating that the input redundancy and output of the DMU is insufficient; λ_i represents the effective front surface composed of all the effective points in the model, when the water resource efficiency falls on the effective front surface, which means that the water resource efficiency of the area is effective. Otherwise, falling below the effective front surface means that the water resource efficiency is invalid. θ represents the distance between the DMU and the effective front surface. The result of CCR model calculation is a comprehensive efficiency value, including technical efficiency and scale efficiency. Technical efficiency refers to the best results we can get with the given investment; scale efficiency refers to the current scale.

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Step 3: Construct a super-efficiency DEA model.

The results of the above two models will produce a situation where multiple units are located on the effective front surface, that is, when the results are all 1, there is no way to sort them. Therefore, in 1993, Andersen and Petersen proposed a super-efficient DEA model, referred to as the SE-DEA model; this model regards all the units located on the effective front as a new system, re-forms a new effective front, and the effective value of the new effective front remains unchanged, so that it can treat all the order of regions is as follows:

minθ:

$$\begin{cases} \sum_{i=1, i \neq i_0}^{n} \lambda_i X_i + S^- = \theta X_0 \\ \sum_{i=1, i \neq i_0}^{n} \lambda_i Y_i - S^+ = Y_0 \\ \lambda_i \geq 0, S^+, S^- \geq 0 \end{cases} \tag{4}$$

In the results of the super-efficiency DEA measurement, the efficiency value below 1 does not change, and for those with an efficiency of 1, the efficiency value must be removed from the setting of 1, so that the result of the calculation will be greater than 1. You can arrange the results.

System GMM model

This paper adopts the system GMM estimation of dynamic panel data, hoping to get a more robust estimation result, the GMM model estimation method is as follows:

Step 1: Assume a linear model:

$$y_i = x_i' \beta + \varepsilon_i = x_{1i}' \beta_1 + x_{2i}' \beta_2 + \varepsilon_i \tag{5}$$

$$\mathrm{E}(x_i \varepsilon_i) = 0 \tag{6}$$

x_{1i} is $k \times 1$, x_{2i} is $r \times 1$, and $l = k + r$. If there are no other constraints, the asymptotically effective estimator of β is the ordinary least squares (OLS) estimate.

Step 2: Now suppose that given a piece of information $\beta_2 = 0$, we can write the model as,

$$y_i = x_{1i}' \beta_1 + \varepsilon_i, \ \mathrm{E}(x_i \varepsilon_i) = 0 \tag{7}$$

How to estimate β_1, one way is OLS estimation. However, this method is not necessarily effective. When there are l constraints in the $\mathrm{E}(x_i \varepsilon_i) = 0$ equation, but the dimension of β_1 is $k < l$, this situation is called transition recognition. There are more moment constraints with $r = l - k$ than free parameters. We call r the number of transition constraints identified.

Le $g(y, z, x, \beta)$ be $l \times 1$ equations, the parameter β is $k \times 1$, and $k < l$, we have:

$$E_{g(y_i, z_i, x_i, \beta_0)} = 0 \tag{8}$$

β_0 is the true value of β. In the above linear model, $g(y, x, \beta) = x(y - x_1' \beta)$. In econometrics, this type of model is called a moment condition model. In statistics, this is called the estimation equation. In addition, we have a linear moment condition model,

$$y_i = z_i' \beta_1 + \varepsilon_i, \ \mathrm{E}(x_i \varepsilon_i) = 0 \tag{9}$$

The dimensions of z_i and x_i are both $k \times 1$, and there are $l \times 1$, $k < l$, if $k = 1$, the model is just recognized, otherwise it is transition recognition. The variable z_i is a part of x_i or a function of x_i. Model (8) can be set as,

$$g(y_i, z_i, x_i, \beta_0) = x(y - z' \beta) \tag{10}$$

Step 3: The sample mean of GMM estimation model (10) is:

$$\bar{g}_n(\beta) = \frac{1}{n} \sum_{i=1}^{n} g_i(\beta) = \frac{1}{n} \sum_{i=1}^{n} x_i (y_i - z_i' \beta) = \frac{1}{n} (X'y - X'Z\beta) \tag{11}$$

The moment estimator of β is to set $\bar{g}_n(\beta) = 0$. For the case where $k < l$ equations are greater than the parameters, the GMM estimation idea is to set $\bar{g}_n(\beta)$ as close as possible to zero.

For $l \times l$ weighting matrix $Wn > 0$, let

$$J_n(\beta) = n \cdot \bar{g}_n(\beta)' W_n \bar{g}_n(\beta) \tag{12}$$

This is a non-negative measure of the length of the vector $\bar{g}_n(\beta)$. For example, if $Wn = 1$, then

$$J_n(\beta) = n \cdot \bar{g}_n(\beta)' \bar{g}_n(\beta) = n \cdot \| \bar{g}_n(\beta)^2 \| \tag{13}$$

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Step 4: GMM estimation is to minimize $J_n(\beta)$, that is, define $\beta_{GMM} = arg_{\beta}J_n(\beta)$.

Note that if k = l, then $\bar{g}_n(\hat{\beta}) = 0$, GMM estimation is the moment estimation method. The first-order conditions of GMM estimation are:

$$0 = \frac{\partial J_n(\hat{\beta})}{\partial \beta} = 2 \cdot \frac{\partial}{\partial \beta}\bar{g}_n(\beta)' W_n \bar{g}_n(\beta) = -2\left(\frac{1}{n}Z'X\right)W_n\left(\frac{1}{n}X'(y - Z\hat{\beta})\right) \quad (14)$$

$$2(Z'X)W_n(X'Z)\hat{\beta} = 2(Z'X)W_n(X'y) \quad (15)$$

Step 5: The GMM of β is estimated as

$$\hat{\beta}_{GMM} = ((Z'X)W_n(X'Z))^{-1}(Z'X)W_n(X'y) \quad (16)$$

RESULTS

Calculation of water resources utilization efficiency

Indicator selection and data sources

Considering the completeness and availability of data, this article uses the capital stock, labor force, and water and energy input of 30 provinces, municipalities, and autonomous regions across the country from 2008 to 2019 (due to the lack of data, excluding Tibet) as input indicators, The GDP and industrial waste gas emissions of each province and city are used as output indicators to evaluate the undesired output of each province, city, and autonomous region. The actual GDP of each province and city is regarded as the expected output. The specific index selection is shown in Table 1.

Table 1 | Index selection

Index	Secondary indicators	Third indicators
Input	Labor force	Number of employees in that year (10,000 people)
	Capital	Capital stock (10,000 yuan)
	Water resources	Total water consumption of all populations in each province (10,000 tons)
Output	Expected output	Real GDP (100 million yuan)
	Undesired output	Sulfur dioxide emissions (10,000 tons) Carbon dioxide emissions (10,000 tons)

Indicator interpretation and data processing

Expected output. This paper selects actual GDP as the desired output variable of all provinces (autonomous regions and municipalities) across the country. In order to avoid the influence of price changes, the GDP deflator is used to uniformly convert the raw data at comparable prices into actual GDP based on 2008. All raw data for GDP come from the statistical yearbooks of China's provinces and municipalities from 2008 to 2019.

Unexpected output. Since the pollution caused by energy consumption is mainly air pollution, and the input-output indicators required by the DEA model should not be too many, this article combines the actual situation in China and finally selects the exhaust gas emissions of sulfur dioxide and carbon dioxide as non-desirable output indicators and specific data on waste gas emissions in various regions come from the 2008 to 2019 China Environmental Yearbook.

Capital stock (K). The 'China Statistical Yearbook' does not list the capital stock of each province, so it needs to be calculated. For the calculation of the capital stock, the commonly used method is the 'perpetual inventory method'. The formula for this method to calculate the capital stock is $K_{i,t} = K_{i-1,t}(1 - \delta_i) + I_i$. In this formula, $K_{i,t}$ represents the capital stock of province i in year t, and δ_i represents the depreciation rate of economic capital goods in province i in the corresponding year. I_i in the formula represents the total amount of province i in year t. Investment amount. When calculating the annual capital stock of each province, this paper uses the calculated capital stock of each province as the base year capital stock of each province. The depreciation of economic capital goods rate δ_i is taken as 9.6%, and the calculation method for the amount of investment in each province in each year is: first, by consulting the 2008–2019 China Statistical Yearbook, the annual fixed asset investment price index and

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the fixed capital formation of each province are obtained. Then the fixed asset investment price index of each year is used to deflate the total fixed capital formation of the corresponding year.

Labor force (L). The number of labor force refers to the effective labor time spent by employees in each province in the production of products. To accurately measure this, the difference in the education level of the labor force should also be considered. However, considering the availability of data, this article ignores the quality differences between different labor forces when calculating the amount of labor input in each province. Instead, it defines labor input as the number of people employed at the end of the year in each province and the number of employees at the end of the previous year average value, unit 10,000 people. The data come from the 'Compilation of Statistical Data for 60 Years of New China' and local statistical yearbooks of various provinces and cities.

Water consumption (CQ). Water consumption refers to the total amount of water consumed by all populations in each province. In terms of data selection, this article selects the relevant data of 30 provinces across the country from 2008 to 2019 for analysis. The data sources are mainly the 2008–2019 China Statistical Yearbook and relevant statistical websites of the water resources department.

Measurement results

In order to analyze the differences of water resources utilization efficiency among the three regions in China, this paper uses the data of 30 provinces except the Tibet Autonomous Region, Hong Kong, Macao and Taiwan from 2008 to 2019, and divides the provinces into three regions: the eastern region mainly includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan and other provinces; the central region mainly includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan and other provinces. It should include Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan and other provinces; the western region mainly includes inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and other provinces. Based on the DEA model with constant returns to scale, the water resources utilization efficiency of Chinese provinces, regions and the whole country from 2008 to 2019 was calculated with the aid of DEAP2.1 software and is shown in Table 2.

It can be seen from Table 2 that Chinese overall average water use efficiency level from 2008 to 2019 is 0.554, and the overall level is not high enough. However, judging from the water use efficiency of various provinces, the water use efficiency of some provinces has improved. For example, the water use efficiency of most regions is on an upward trend, indicating that the level of water use has improved. From the perspective of the average water use efficiency of 30 provinces in 13 years, the five provinces with the highest average water use efficiency are Shanghai, Tianjin, Shandong, Liaoning, and Beijing, all of which are higher than 0.8. The highest are Shanghai and Beijing, and the water use efficiency of the two provinces has reached an effective value of more than 1 during the 12 years. The five provinces with the lowest average water use efficiency are Xinjiang, Ningxia, Tibet, Guangxi, and Qinghai, all of which are lower than 0.4. Among them, Qinghai has the lowest water use efficiency with only 0.248; from the overall water use efficiency of each province. It can be seen from the efficiency value that the water use efficiency of different provinces in Chinese is quite different. The areas with high water use efficiency are concentrated in the eastern region. The average value of the eastern region is 0.816, the average value of the central region is 0.455, and the average value of the western region is 0.364. It can be seen that there are large differences between different regions, so it is necessary to study the influencing factors that affect the efficiency of water use, so as to provide a theoretical reference for the implementation of differentiated policies. The following will use empirical analysis to study the influencing factors.

The impact of environmental regulations on water resources utilization efficiency

Indicator selection and data sources

The explained variable. Water use efficiency, the data come from the calculation results above in this article.

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Table 2 | Calculating results of water resources efficiency in various regions of China

	Region	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean
Eastern	Beijing	0.935	0.958	0.976	0.984	0.993	1.087	1.124	1.145	1.155	1.187	1.201	1.246	1.083
	Tianjin	0.719	0.721	0.742	0.763	0.792	0.813	0.836	0.873	0.898	0.921	0.949	0.965	0.833
	Hebei	0.556	0.569	0.574	0.591	0.599	0.602	0.631	0.658	0.689	0.706	0.718	0.745	0.637
	Liaoning	0.732	0.747	0.769	0.778	0.798	0.809	0.821	0.848	0.865	0.893	0.926	0.968	0.830
	Shanghai	0.912	0.924	0.935	0.947	0.953	0.975	0.998	1.077	1.104	1.138	1.152	1.209	1.027
	Jiangsu	0.706	0.711	0.723	0.724	0.743	0.748	0.755	0.767	0.779	0.788	0.797	0.818	0.755
	Zhejiang	0.711	0.725	0.734	0.756	0.776	0.787	0.799	0.802	0.814	0.825	0.853	0.876	0.788
	Fujian	0.676	0.685	0.701	0.722	0.732	0.757	0.777	0.798	0.814	0.841	0.856	0.886	0.770
	Shandong	0.733	0.747	0.761	0.785	0.798	0.816	0.836	0.849	0.864	0.878	0.899	0.915	0.823
	Guangdong	0.712	0.723	0.732	0.736	0.751	0.763	0.775	0.787	0.794	0.818	0.834	0.854	0.773
	Hainan	0.541	0.575	0.595	0.614	0.629	0.654	0.678	0.688	0.707	0.723	0.733	0.748	0.657
Eastern mean		0.721	0.735	0.749	0.764	0.779	0.801	0.821	0.845	0.862	0.883	0.902	0.930	0.816
Central	Shanxi	0.323	0.329	0.335	0.346	0.359	0.367	0.376	0.389	0.393	0.398	0.401	0.413	0.369
	Jilin	0.355	0.363	0.368	0.374	0.381	0.392	0.403	0.421	0.436	0.453	0.471	0.496	0.409
	Heilongjiang	0.551	0.561	0.572	0.587	0.596	0.613	0.618	0.633	0.641	0.658	0.667	0.683	0.615
	Anhui	0.375	0.381	0.392	0.398	0.407	0.412	0.422	0.435	0.439	0.446	0.459	0.462	0.419
	Jiangxi	0.377	0.385	0.391	0.397	0.405	0.417	0.428	0.439	0.453	0.467	0.478	0.489	0.427
	Henan	0.355	0.363	0.369	0.374	0.384	0.398	0.404	0.418	0.429	0.435	0.453	0.462	0.404
	Hubei	0.477	0.479	0.486	0.494	0.505	0.518	0.528	0.543	0.557	0.568	0.578	0.593	0.527
	Hunan	0.423	0.434	0.441	0.448	0.456	0.467	0.473	0.488	0.494	0.509	0.519	0.524	0.473
Central mean		0.405	0.412	0.419	0.427	0.437	0.448	0.457	0.471	0.480	0.492	0.503	0.515	0.455
Western	Inner Mongolia	0.361	0.363	0.366	0.371	0.373	0.379	0.384	0.389	0.393	0.399	0.404	0.418	0.383
	Guangxi	0.297	0.301	0.312	0.315	0.322	0.327	0.344	0.354	0.367	0.373	0.389	0.396	0.341
	Chongqing	0.464	0.476	0.482	0.489	0.497	0.509	0.516	0.532	0.544	0.562	0.581	0.596	0.521
	Sichuan	0.304	0.313	0.326	0.331	0.339	0.347	0.358	0.369	0.378	0.388	0.392	0.395	0.353
	Guizhou	0.294	0.298	0.309	0.317	0.325	0.331	0.346	0.356	0.367	0.372	0.385	0.392	0.341
	Yunnan	0.317	0.323	0.334	0.346	0.352	0.361	0.374	0.388	0.395	0.406	0.424	0.436	0.371
	Shaanxi	0.375	0.379	0.385	0.394	0.399	0.414	0.426	0.442	0.465	0.479	0.485	0.489	0.428
	Gansu	0.359	0.364	0.366	0.372	0.379	0.384	0.394	0.398	0.403	0.417	0.427	0.437	0.392
	Qinghai	0.211	0.214	0.222	0.233	0.235	0.246	0.241	0.256	0.269	0.274	0.284	0.294	0.248
	Ningxia	0.274	0.285	0.291	0.299	0.302	0.313	0.318	0.322	0.331	0.344	0.349	0.355	0.315
	Xinjiang	0.261	0.269	0.278	0.296	0.302	0.319	0.322	0.329	0.335	0.346	0.347	0.354	0.313
Western mean		0.320	0.326	0.334	0.342	0.348	0.357	0.366	0.376	0.386	0.396	0.406	0.415	0.364
National mean		0.490	0.499	0.509	0.519	0.529	0.544	0.557	0.573	0.586	0.600	0.614	0.630	0.554

Explaining variables. Environmental regulation (ER). As a public product, water resources have not obtained prices and high-efficiency allocation in the market system, which has led to the abuse of water resources by industrial enterprises, resulting in water waste and pollution. As the main body of macroeconomic regulation and control, the government's policies, behaviors and intervention measures to the main body of market economy will inevitably have an impact on enterprises and society. In recent years, the Chinese government has gradually increased the entry barriers of various industries through the pollution discharge fee system and the pollution discharge trading system, using the force mechanism to optimize the industrial structure, and promote the coordinated development of economic society and environmental protection. This shows that government environmental regulations will also have an impact on industrial water efficiency. This paper uses the ratio of China's regional pollution charges to regional GDP to measure the intensity of local environmental regulations.

The level of economic development (GDP). In 1996, Panayotou proposed the Environmental Kuznets Curve (EKC), pointing out that the environmental quality presents a U-shaped curve relationship with economic development

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that first declines and then rises. With the rapid development of Chinese industrialization, along with increasingly serious water pollution, there is still a negative correlation between water pollution and the level of economic development. This article believes that the level of inter-provincial economic development is one of the reasons for the regional differences in water resource efficiency. On this basis, the completed investment in wastewater treatment projects and the total amount of water supply are further selected as the representative value of the inter-provincial economic development level, and the impact of the economic development level of different provinces (cities, autonomous regions) on water resources efficiency is investigated.

Industrial structure (US). The formation of water consumption structure is largely affected by the industrial structure, and a reasonable adjustment of the proportion of each industry has a great impact on the improvement of water resource utilization efficiency. The indicators used in this article to study the impact of industrial structure are the proportion of the primary industry (FUS) and the proportion of the secondary industry (SUS).

Water structure (QS). Different aspects of society have different demands for water resources and different utilization levels of water resources. Therefore, a reasonable allocation of water resources is of great significance to improving the utilization of water resources. This paper selects agricultural water consumption (AQ), industrial water consumption (IQ), and domestic water consumption (LQ) as indicators of water consumption. Some documents believe that factors such as import and export trade, water prices, and water resources policies will also affect regional water consumption. Resource utilization efficiency has an impact, but due to the unavailability of data and indicators that are difficult to measure, indicators such as water prices, water resources policies, and water conservation awareness will not be considered in the measurement model of this article.

Technology level (TE). This paper will select the research and experimental development funds of industrial enterprises above designated size as factors of scientific and technological progress to study its impact on industrial water resources utilization efficiency. Scientific research and development and innovation capabilities are playing an increasingly important role in all aspects of society today. The development and progress of science and technology can bring more effective water-saving technologies and equipment to the use of industrial water resources, and can also improve the development of water resources and management level.

This article combines the existing literature and considers the availability of data, and compares the economic development level (GDP), environmental regulation (ER) and its square terms, the proportion of the primary industry (FUS), and the proportion of the secondary industry (SUS), Total agricultural water (AQ), total industrial water (IQ), total domestic water (LQ) and technological level (TE) as explanatory variables, the sample interval is 2008–2019, and the following regression equation is established:

$$\begin{aligned}\ln WRE = &\alpha + \beta_1 \ln GDP_i + \beta_2 \ln ER_i + \beta_3 \ln ER^2 \\ &+ \beta_4 \ln FUS_i + \beta_5 \ln SUS_i + \beta_6 \ln AQ_i \\ &+ \beta_7 \ln IQ_i + \beta_8 \ln LQ_i + \beta_9 \ln TE_i + \mu\end{aligned} \quad (17)$$

Measurement results

The estimation results of the model based on the system GMM model estimation method are shown in Table 3.

For the environmental regulation variables that this article focuses on, the model estimation results show that the impact of environmental regulation on China's water resources efficiency conforms to a 'U'-shaped nonlinear relationship, and has passed the 1% significance test. This article believes that there is an obvious dependency between water resource utilization efficiency and environmental

Table 3 | Regression results

Explanatory variables	Parameter estimate	T statistics	*P* value
LnGDP	0.0125***	−5.129	0.0012
LnER	−0.0231***	−4.092	0.0001
$(\text{LnER})^2$	0.0018***	3.239	0.0011
LnFUS	−0.1312***	−3.521	0.0013
LnSUS	−0.0678***	−4.167	0.0002
LnAQ	−0.1534***	−3.198	0.0212
LnIQ	−0.2188***	−7.342	0.0014
LnLQ	−0.0233***	−4.118	0.0012
LnTE	0.1312	0.324	0.1712

Note: ***, **, * are significant under the conditions of 1, 5, and 10% respectively.

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regulations, but different environmental regulation intensities have different impact mechanisms on water resource utilization efficiency. When the environmental regulations formulated by the government are weak and do not pose pressure on the competitiveness of enterprises in the market, enterprises will often spend part of the funds for pollution control due to short-term profit considerations, which is an additional increase in pollution control expenditures showing that more 'follow the cost effect'. As the intensity of environmental regulations increases to the 'inflection point' level, the 'reverse mechanism' of pollution control has gradually formed. The cost of controlling pollution emissions through the end has become higher and higher, which not only reduces the profit level of enterprises, but also faces pressure to reduce emissions is also increasing. Therefore, industries with 'high energy consumption and high pollution' will either increase investment in upgrades or be gradually eliminated or transferred or go to areas with weaker environmental regulations. In this way, areas with strong environmental regulations tend to have high water resource utilization efficiency, while areas with weaker environmental regulations tend to decline in water resource utilization efficiency (Zhang *et al.* 2011).

The coefficient of economic development level is positive and has passed the significance test at the 1% level, which shows that the economic development level, that is, per capita GDP, has a significant positive effect on water resources efficiency. With the rapid economic development and the acceleration of industrialization, people are more and more aware of the importance of water saving, and they also have sufficient economic strength to develop new technologies and adopt new equipment to effectively improve water-saving technologies and improve the utilization efficiency of industrial water resources. This is also consistent with the empirical results that the overall efficiency value of the developed central and eastern regions is significantly higher than that of the relatively backward central and western regions.

The coefficient of scientific and technological progress is positive, but the impact of scientific and technological input on water resources efficiency is limited and insignificant, which indicates that the technical support power in water resources development is insufficient. This is mainly related to the large amount of technology investment but is of insufficient quality. Specifically, first, the continuous expansion of regional industrialization, urbanization, and agriculturalization has consumed a large amount of scientific and technological input costs, squeezing the innovation of water-saving technology, water pollution prevention technology and water resource development technology to a certain extent. As a result, a large amount of investment in science and technology cannot promote the improvement of water efficiency. Second, the overall economic development strength is lagging, and it is in the early stage of industrial transfer. The high-tech energy-saving and environmental protection industries are mainly concentrated in the eastern region. Generally speaking, although the significance test has not passed, the positive coefficient indicates that the positive effect of scientific and technological progress is gradually reflected.

The industrial structure (the proportion of primary and secondary industries) and the utilization efficiency of water resources are negatively correlated. The regression coefficient of the primary industry is -0.1312, which means that the proportion of agriculture will drop by 1%, and the efficiency of water use will increase by 0.1312 percentage points. The regression coefficient corresponding to the proportion is -0.0678, which means that for every 1% drop in the proportion of industry, the water use efficiency will increase by 0.0678%. In China, agriculture and industry are major water users, and the current recycling rate of industrial water resources and the utilization rate of agricultural irrigation water in China are relatively low. In particular, the traditional agricultural irrigation mode consumes a large amount of water resources and also causes a large amount of water. Water resources are wasted, which makes the utilization efficiency of water resources have a large gap from the optimal utilization rate. It can be seen that scientific and reasonable adjustments to the industrial structure can not only improve the utilization efficiency of water resources, but are also important for the construction of a water-saving society.

Water consumption structure. There is a negative correlation between water consumption structure and water resource efficiency, among which domestic water and industrial water have a relatively large impact. In other words, whether it is agriculture, industry, life, or ecological water use, it has a certain negative impact on the environment, and the impact of ecological water use is relatively low, which is consistent with the purpose of improving water

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use efficiency and improving water use structure. It is possible to consider the factors affecting regional differences in water resources efficiency from the perspective of the water consumption of specific industries in combination with the industrial water use structure.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This paper uses the super-efficiency DEA model to measure the water resources efficiency of 30 provinces (cities, autonomous regions) in China, evaluates the overall situation of China's water resources efficiency, and then uses the system GMM model to regression analyze the impact of environmental regulations on China's regional water resources efficiency The extent and direction of the project, the conclusions are as follows:

(1) The overall level of water use efficiency in China is not high enough. The five provinces with the highest average water use efficiency are Shanghai, Tianjin, Shandong, Liaoning, and Beijing. The five provinces with the lowest average water use efficiency are Xinjiang, Ningxia, Tibet, Guangxi and Qinghai. There is a big difference in resource utilization efficiency. The areas with higher water use efficiency are concentrated in the eastern region, then the central region, and finally the western region.

(2) There is an obvious dependence between water resource utilization efficiency and environmental regulations, but different environmental regulation intensities have different impact mechanisms on water resource utilization efficiency. When the strength of environmental regulations is weak and does not pose pressure on the competitiveness of the company in the market, the company will often spend part of the funds for pollution control out of short-term profit considerations. This additional expenditure on pollution control will increase more and more showing 'following the cost effect'. As the intensity of environmental regulations increases to the 'inflection point' level, the 'reversing mechanism' of pollution control has gradually formed. The cost of controlling pollution emissions through to the end has become higher and higher, which not only reduces the profit level of enterprises, but also faces the problems. Pressure to reduce emissions is also increasing. That is, there is a 'U'-shaped relationship between the intensity of environmental regulation and the efficiency of water resources utilization. That is, weaker intensity of environmental regulation is not conducive to the improvement of water resource utilization efficiency, but when the intensity of environmental regulation crosses the 'inflection point', it can promote improvement of water utilization efficiency.

(3) Other influencing factors indicate that the level of economic development has a very significant positive effect on water resources efficiency, and the efficiency value calculated in the previous article. The overall efficiency value of the developed central and eastern regions is significantly higher than that of the relatively backward central and western regions. The empirical results are consistent; the coefficient of scientific and technological progress is positive, but the impact of scientific and technological input on water resources efficiency is limited and insignificant. This indicates that the technical support power in the development of water resources is insufficient, but the positive coefficient indicates that the positive effect of scientific and technological progress is gradually reflected; the industrial structure (the proportion of primary and secondary industries) and the utilization efficiency of water resources show a negative correlation, as the proportion of agriculture declines, the utilization efficiency of water resources will increase, and as the proportion of industry declines, the utilization efficiency of water resources will increase; the structure of water use and the efficiency of water resources will change. There is a negative correlation, in which the impact of domestic water and industrial water is relatively large, whether it is agriculture, industry or life, it has caused a certain negative impact on the environment.

Recommendations

Based on the above analysis and conclusions, this article puts forward the following recommendations based on the actual development of China's region.

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First, adhere to the concept of green development and continue to promote the improvement of the economic level. Improve the government's macro-control, increase environmental regulation of heavy pollution industries such as food, textile, paper, energy and chemical industries, adjust the industrial layout, and formulate and implement funding and technology support for emerging industries such as environmental protection and service industries. In addition, improve the level of corporate innovation and management, increase the research and development and application of advanced technologies, implement corporate environmental responsibilities, and create an ecological industrial chain (Zhao *et al.* 2014; Wang 2015; Wang & Tan 2020; Wang *et al.* 2020).

Second, the government should do a good job of support and guidance, increase investment in science and technology, cultivate technical talents, improve the level of science and technology, and provide technical support for water resources efficiency, with a view to building the most stringent water resources management system, early control and use of water resources, and timely levy an environmental tax outside the price to reduce water pollution, and gradually establish and improve a water resource property and use control system. For the eastern region, the government taps water-saving potential, improves sewage treatment capacity and reuses water capacity as much as possible, increases environmental protection publicity, and promotes the construction of a water-saving society. On the basis of improving the level of science and technology, the central and western regions strengthen environmental monitoring and government supervision; establish a water resource efficiency evaluation system and punishment mechanism to better promote the improvement of water resource efficiency (Dong *et al.* 2014; Li 2014; Ren *et al.* 2016).

Third, promote the improvement of industrial water use structure on the basis of economic development and technological improvement. Improve the irrigation coefficient and irrigation efficiency for agricultural water; improve sewage treatment capacity and circulating water use capacity for industrial water, and improve the efficiency of industrial water resources; for domestic water, strengthen environmental protection publicity, expand the scope of publicity, and improve the public's water-saving awareness. Ecological water, rationally and reasonably promote the use of ecological water, improve the water resources supervision and management mechanism, promote the further improvement of the structure of water resources, promote harmony between human and water, and improve the efficiency of water resources (Sun *et al.* 2011; Zhu *et al.* 2011; Wang *et al.* 2017a, 2017b).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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