



Analysis of the water use efficiency using super-efficiency data envelopment analysis

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Abstract

Data envelopment analysis (DEA) is a linear programming and production theory-based nonparametric approach that is generally used for efficiency analysis. Older DEA models, such CCR and BCC, can only identify decision-making units (DMUs) efficient or inefficient. The super-efficiency DEA model enables efficient DMUs to be ranked. A change in efficient DMUs can be measured using Malmquist index model, and the Malmquist productivity change index can be decomposed multiplicatively into an efficiency-change component (Effch) and a technical change component (Techch). This paper analyzes the water use efficiency in Shandong Province between 2006 and 2015 using Malmquist productivity index (TFP). The results show that: (1) the mean of super-efficiency scores of 17 cities in Shandong Province for the period 2006–2015 is between 0.965 and 2.760; (2) the water use efficiency was positive in 2006–2007, 2007–2008, and 2013–2014; however, it was negative in the other periods between 2006 and 2015; and (3) technical change is the key influencing factor on water use efficiency of 17 cities in Shandong Province. So, we suggest that Shandong Province encourage technological innovation to promote water use efficiency.

Keywords Water use efficiency · Super-efficiency DEA · Malmquist index · Shandong Province

Introduction

Water is a basic natural resource and a strategic economic resource. It is essential to biodiversity, an ecological balance, socioeconomic development, and environmental goods or amenities. Nevertheless, humans can only use 0.26% of the global water resources. Water resources are not evenly distributed in time and space in most countries and regions,

and approximately 80 countries, accounting for 40% of the global population, have severe water shortages. Improving water use efficiency is an effective way to address a water shortage, and it is the foundation for maintaining the sustainable development and utilization of a water resource (Zoebl 2006; Linderson et al. 2007; Allan 1999; Bithas 2008). So, water use efficiency has become a hot issue in water science research, and national governments, water policy-makers, and related industries have become focused on these issues. Water use efficiency has two forms: technical and allocative. Technical efficiency, or, as Farrell called it, physical efficiency (Farrell 1957), is defined either as producing the maximal level of output given an input, or as using the minimal level of input given an output and input mix (Lovell 1993; Cornwell and Schmidt 1996). Allocative efficiency, or, as Farrell called it, price efficiency (Farrell 1957), means to the ability to combine inputs and outputs in optimal proportions on the basis of prevailing prices (Lovell 1993; Badunenko et al. 2008). National governments believe that it will be possible to have ‘better water management’ and ‘achieve more with less’, and policy-making must be considered in order to enhance water use efficiency (Allan 1999).

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This ‘better water management’ is understood as gains for water resources allocation and technical efficiency.

Water use efficiency is a social, economic, or ecological benefit for a unit of water. Water use for a single purpose is a major research perspective in water use efficiency. Examples are water use efficiency in irrigated agriculture (Singh 2007; Christian-Smith et al. 2012), industrial water efficiency (Mousavi et al. 2016; Schlei-Peters et al. 2015; Bindra et al. 2003), and urban water resource utilization efficiency (Shi et al. 2015), etc.

The main methods for measuring water use efficiency are the unit water output, value-added unit water output, and total factor productivity (TFP) methods. The unit water output or value-added of unit water output methods cannot adequately reflect the actual condition of water use efficiency because they are subjective, use a single factor input index and are not always meaningful (Zoebl 2006).

The total factor productivity of water use efficiency is the ratio of the minimum water consumption to the actual water consumption in the measurement area. Data envelopment analysis (DEA) is a linear programming and production theory-based mathematical approach that aims to measure how efficiently selected DMUs generate selected outputs by using selected inputs as the scope of comparison (Charnes et al. 1978; Egilmez and McAvoy 2013). The original work on DEA is the original DEA-CRS (constant-returns-to-scale) model provided by Charnes et al. (1978), which is later extended to a variable-returns-to-scale (VRS) model by Banker et al. (1984), called CCR (initial of Charnes Cooper and Rhodes) and BCC (initial of Banker Charnes and Cooper), respectively. DEA is generally used to measure the efficiency of a resource’s utilization by its total input and output and can measure the relative effectiveness and rank the efficiency of a resource’s utilization. This includes land utilization efficiency (Chen et al. 2016), the efficiency of electric power production, and distribution processes (Khalili-Damghani and Shahmir 2015), agricultural water resources efficiency (Mousavi-Avval et al. 2011; Speelman et al. 2008), industrial water resources efficiency, and urban water supply efficiency (Molinos-Senante et al. 2016; Byrnes et al. 2010; Aida et al. 1998), and so on. But a DMU is considered to be efficient in most DEA models like CCR and BCC if its performance relative to other DMUs cannot be improved. Therefore, Andersen and Petersen (1993) proposed the super-efficiency DEA (SE-DEA) model, in which the efficiency scores (i.e., $\theta = 1$) or the super-efficiency scores (i.e., $\theta > 1$) of DMUs can be obtained. Meanwhile, the efficiency scores of DMUs in most DEA models like CCR and BCC cannot be analyzed dynamically in different periods. The DEA-based Malmquist index model by Färe and Grosskopf (1994) can be implemented.

This paper applies the super-efficiency DEA and the Malmquist index to analyze the water use efficiency in

Shandong province, China. Firstly, the CCR, BCC, and SE-DEA models are applied to a comparative analysis of the water use efficiency of 17 cities in Shandong Province for the period 2006–2015, and the DEA-based Malmquist index method is used for a dynamic analysis. Then, the change roots of the water use efficiency during the 11th and 12th Five-year Plan periods are identified by means of decomposing the Malmquist index into a technical progress component and a technical efficiency component, and further decomposing the technical efficiency component into a pure technical efficiency component and a scale efficiency component.

Methodology

Super-efficiency DEA model

The super-efficiency DEA method ranks the performance of efficient DMUs. The basic idea of SE-DEA model is to compare the unit under evaluation with a linear combination of all other units in the sample, i.e., the DMU itself is excluded (Sun and Lu 2005). In that case, an efficiency score that exceeds unity is obtained for the unit because the maximum proportional increase in inputs preserves efficiency (Andersen and Petersen 1993; Matthias and Maik 2005).

The SE-DEA model may be expressed as

$$\begin{aligned} & \min \theta \\ & \text{s.t.} \begin{cases} \sum_{\substack{k=1 \\ k \neq j}}^n \lambda_k X_k + s^- = \theta X_j \\ \sum_{\substack{k=1 \\ k \neq j}}^n \lambda_k Y_k - s^+ = Y_j \\ \lambda_k \geq 0, \quad k = 1, 2, \dots, n \\ s^- \geq 0, \quad s^+ \geq 0 \end{cases} \quad (1) \end{aligned}$$

where θ is a scalar that defines the share of the j th DMU’s input vector, which is required in order to produce the j th DMU’s output vector within the reference technology; X_j is an m -dimensional input vector and Y_j is an s -dimensional output vector for the j th unit; and λ is an intensity vector in which λ_k denotes the intensity of the k th unit.

The advantage of the SE-DEA model is that it permits us to rank efficient DMUs. Similar to CCR, it can provide a super-efficiency rating for efficient units. Meanwhile, the efficiency score of the inefficient DMUs remains consistent with CCR.

Malmquist index

The concept of Malmquist index was first introduced by Malmquist (1953), which was developed by Caves et al.

(1982) who defined the output-based Malmquist productivity index as the ratio of two output distance functions.

Supposing that each DMU_j produces a vector of outputs $Y_j^t = (Y_{1j}^t, Y_{2j}^t, \dots, Y_{sj}^t)$ by using a vector of inputs $X_j^t = (X_{1j}^t, X_{2j}^t, \dots, X_{mj}^t)$ at each time period $t = 1, 2, \dots, T$, and following Shephard (1970) or Färe (1988), the output distance function is defined at t as

$$D_0^t(x^t, y^t) = \inf \{ \theta : (x^t, y^t/\theta) \in S^t \} \tag{2}$$

The production is technically efficient if $D_0^t(x^t, y^t) = 1$, and it is technically inefficient if $D_0^t(x^t, y^t) < 1$.

The Malmquist index measures the productivity change in a DMU between two time periods. Following Färe et al. (1989, 1992), this index could be also written in an equivalent way as

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \times \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \tag{3}$$

$$M_0(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{S_0^t(x^t, y^t)}{S_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^{t+1}(x^{t+1}, y^{t+1} | VRS)}{D_0^t(x^t, y^t | VRS)} \times \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \tag{7}$$

where M_0 measures the productivity change in DMU₀ between period t and $t + 1$.

The Malmquist productivity change index is decomposed multiplicatively into Effch and Techch (Färe et al. 1992, 2011):

$$Effch = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \tag{4}$$

and

$$Techch = \left[\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_0^t(x^t, y^t)}{D_0^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \tag{5}$$

so that $M_0 = Effch \times Techch$.

$M_0 > 1$ indicates the progress in the total factor productivity of the DMU₀ from period t to $t + 1$; while $M_0 = 1$ and $M_0 < 1$ indicate the status quo and decay in the total factor productivity, respectively.

Färe et al. (1994) used an enhanced decomposition of Malmquist index developed in Eq. (3), that is based on CRS. This enhanced decomposition takes the efficiency-change component and decomposes it into a pure efficiency-change

component (calculated relative to the variable-returns technologies) and a residual scale component (i.e., scale efficiency). Scale efficiency was introduced in Färe et al. (1983), but is often attributed to Banker (1984), who focused on what he called the most productive scale size, i.e., the tangency between the VRS and CRS technologies. Färe et al. (2011) definition is

$$S_0(x, y) = \frac{D_0(x, y | VRS)}{D_0(x, y | CRS)} \tag{6}$$

where $D_0(x, y | CRS)$ is estimated relative to the CRS reference technology (where the only restriction on the intensity variables is that they take nonnegative). $D_0(x, y | VRS)$ is a similar definition but with VRS.

The enhanced decomposition of Malmquist index may now be written as (Färe et al. 1994):

so that $M_0 = Sech \times Pech \times Techch$, where $Effch = Sech \times Pech$. The Effch term refers to efficiency change calculated under CRS, and Pech is efficiency change calculated under VRS.

Case study

Data and index

Water resources, as a kind of natural resource, and other production factors together make products. Reasonable input and output indexes were chosen based on whether an index had no linear relationship, the availability of data, and research achievements in water use efficiency (Hu et al. 2006; Yang et al. 2015; Wang et al. 2015; Deng et al. 2016). Taking agricultural water consumption, industrial water consumption, domestic water consumption, total COD discharge quantity, investment in fixed assets of the whole society, and labor of the whole society as input index, GDP and grain yield are taken as output index.

Here, using super-efficiency DEA-based Malmquist index model, we analyzed water use efficiency in Shandong

Province from 2006 to 2015 with data from the Shandong Statistic Yearbook.

Static analysis on water use efficiency in Shandong Province

The productive efficiency score, pure technical efficiency, and scale efficiency of 17 cities in Shandong Province in 2015 were obtained using the DEAP2.1 software. The super-efficiency score was obtained using the Efficiency Measurement System software, Version 1.3.0, and the results are shown in Table 1. Table 1 also shows changes in the returns to scale that were obtained with BCC, and ranks of super-efficiency scores that were obtained with SD-DEA.

1. Results from CCR and BCC

Table 1 shows that Jining, Tai'an, Rizhao, Laiwu, Linyi, Liaocheng, and Binzhou are categorized as being relatively inefficient (i.e., efficiency scores that is less than unity), with the CCR model giving efficiency scores of 0.901, 0.850, 0.792, 0.717, 0.853, 0.904, and 0.882, respectively. The water use efficiency of relatively inefficient units can be ranked according to their productive efficiency score, pure technical efficiency, and scale efficiency.

The other regions are categorized as being relatively efficient (i.e., efficiency score equal to unity), also, their productive efficiency score, pure technical efficiency, and scale

efficiency are equal to unity according to the CCR or BBC model. However, the CCR or BBC model cannot fully rank all of the relatively efficient DMUs.

From the point of view of scale efficiency, the change in the returns to scale of Jining and Linyi is decreasing, implying that there is too much input into these two cities, and the rational allocation of resources is necessary to improve their water use efficiency. However, the change in the returns to scale of Tai'an, Rizhao, Laiwu, Liaocheng, and Binzhou is increasing, indicating that the input and scale do not match, and the scale of production needs to expand in these cities.

2. Results from SE-DEA

The SE-DEA model only analyzes DMUs that the efficiency scores are unity in the CCR model, while DMUs that the efficiency scores less than unity are unchanged. In Table 1, the super-efficiency scores of Jining, Tai'an, Rizhao, Laiwu, Linyi, Liaocheng, and Binzhou are identical with that of CCR. However, the super-efficiency scores of Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weifang, Weihai, Dezhou, and Heze are greater than unity. Therefore, the SE-DEA model is able to assess and rank all DMUs. The rank of water use efficiency is successively as follows: Qingdao, Dezhou, Weihai, Heze, Dongying, Jinan, Yantai, Weifang, Zaozhuang, Zibo, Liaocheng, Jining, Binzhou, Linyi, Tai'an, Rizhao, and Laiwu in 2015.

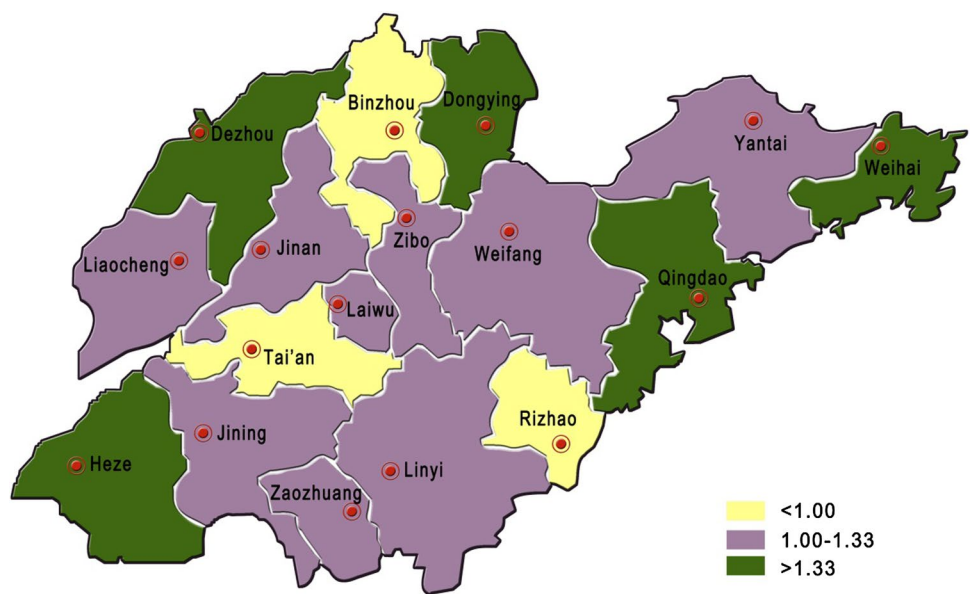
Table 1 Water use efficiency scores of 17 regions of Shandong Province in 2015 and their rank

DMU (region)	CCR	BCC		Returns to scale change	SE-DEA	
	Productive efficiency	Pure technical efficiency	Scale efficiency		Super-efficiency	Rank
Jinan	1.000	1.000	1.000	Constant	1.409	6
Qingdao	1.000	1.000	1.000	Constant	3.323	1
Zibo	1.000	1.000	1.000	Constant	1.042	10
Zaozhuang	1.000	1.000	1.000	Constant	1.059	9
Dongying	1.000	1.000	1.000	Constant	1.451	5
Yantai	1.000	1.000	1.000	Constant	1.265	7
Weifang	1.000	1.000	1.000	Constant	1.067	8
Jining	0.901	0.914	0.986	Decreasing	0.901	12
Tai'an	0.850	0.863	0.985	Increasing	0.850	15
Weihai	1.000	1.000	1.000	Constant	2.020	3
Rizhao	0.792	0.928	0.853	Increasing	0.792	16
Laiwu	0.717	1.000	0.717	Increasing	0.717	17
Linyi	0.853	0.854	0.999	Decreasing	0.853	14
Dezhou	1.000	1.000	1.000	Constant	2.698	2
Liaocheng	0.904	0.916	0.987	Increasing	0.904	11
Binzhou	0.882	1.000	0.882	Increasing	0.882	13
Heze	1.000	1.000	1.000	Constant	1.995	4

Table 2 Super-efficiency scores of 17 cities in Shandong Province for the period 2006–2015

Region	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Mean
Jinan	0.954	0.960	0.905	0.967	0.997	1.241	1.143	1.271	1.337	1.409	1.118
Qingdao	0.964	1.114	1.348	1.317	1.355	1.708	1.823	1.797	1.573	3.323	1.632
Zibo	0.907	0.950	1.097	1.080	1.021	1.104	0.938	1.040	1.032	1.042	1.021
Zaozhuang	1.780	1.396	1.288	1.144	1.085	1.043	1.044	1.024	1.111	1.059	1.197
Dongying	1.724	1.613	1.958	1.701	1.636	1.734	1.742	1.584	1.541	1.451	1.668
Yantai	0.881	0.965	1.209	1.205	1.244	1.175	1.372	1.240	1.345	1.265	1.190
Weifang	1.038	1.115	1.145	1.122	1.139	0.980	1.109	1.020	1.202	1.067	1.094
Jining	1.007	1.106	1.093	1.033	1.028	1.302	0.955	0.960	0.981	0.901	1.037
Tai'an	1.218	1.187	1.046	1.004	1.001	0.777	0.824	0.835	0.912	0.850	0.965
Weihai	2.216	1.958	1.917	1.722	1.675	1.942	1.786	2.011	2.224	2.020	1.947
Rizhao	1.375	1.130	0.945	0.965	1.389	0.833	0.768	0.915	0.837	0.792	0.995
Laiwu	1.499	2.353	1.808	1.081	0.984	0.904	0.724	0.847	0.670	0.717	1.159
Linyi	1.301	1.351	1.298	1.134	1.207	0.850	0.831	0.871	0.908	0.853	1.060
Dezhou	2.080	3.218	2.788	5.225	1.685	1.650	1.525	2.340	4.389	2.698	2.760
Liaocheng	1.876	1.313	1.173	0.967	1.047	1.506	0.946	0.982	0.957	0.904	1.167
Binzhou	0.949	0.942	1.008	0.922	0.972	1.179	1.012	0.921	0.892	0.882	0.968
Heze	1.297	1.348	1.458	1.504	1.869	1.672	1.689	1.872	1.965	1.995	1.667

Fig. 1 Spatial distribution of super-efficiency scores of 17 cities in Shandong Province for the period 2006–2015



The SE-DEA super-efficiency scores of 17 cities in Shandong Province for the period 2006–2015 are given in Table 2. And the spatial distribution of super-efficiency score means of 17 cities in Shandong Province is shown in Fig. 1.

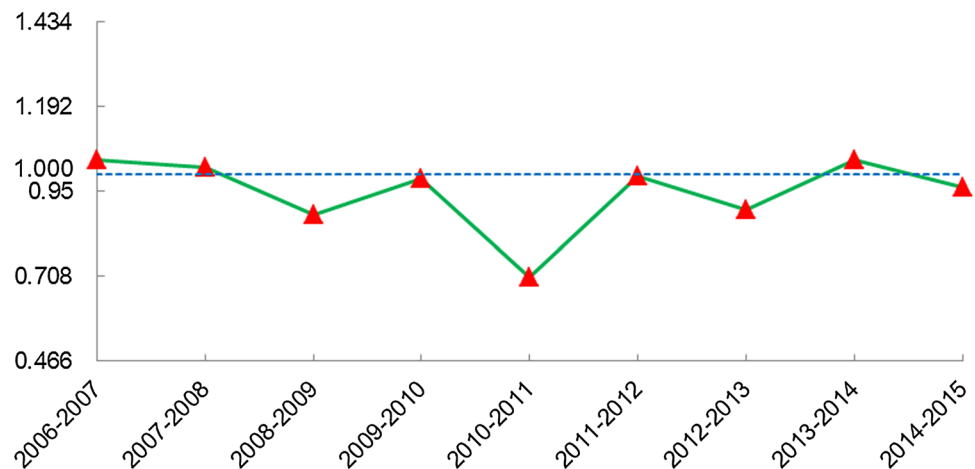
Table 2 shows that the super-efficiency scores of 17 cities in Shandong Province for the period 2006–2015 range between 0.670 and 5.225. As shown in Fig. 1, according to the super-efficiency score means, the cities can be divided

into three categories: low efficiency, medium efficiency, and high efficiency. The low efficiency category includes cities whose mean super-efficiency scores is less than unity in Binzhou, Tai'an, and Rizhao. The high efficiency category includes cities whose mean score is greater than 1.33 in Dezhou, Dongying, Weihai, Qingdao, and Heze. The other cities belong to medium efficiency category, which includes cities with a mean score between 1.00 and 1.33.

Table 3 Malmquist index of 17 cities in Shandong Province for the period 2006–2015

Period	Jinan	Qingdao	Zibo	Zaozhuang	Dongying	Yantai	Weifang	Jining	Tai'an
2006–2007	1.049	1.102	1.092	0.865	1.035	1.162	1.07	1.077	1.073
2007–2008	1.021	1.122	1.114	0.984	1.232	1.06	1.058	1.002	0.994
2008–2009	0.951	0.876	0.825	0.805	0.787	0.989	0.937	0.791	0.976
2009–2010	1.028	1.105	0.942	0.947	1.018	1.081	1.027	0.991	1.07
2010–2011	0.848	0.703	0.878	0.899	0.889	0.768	0.57	0.678	0.466
2011–2012	1.024	1.029	1.006	0.997	1.149	1.1	0.997	0.851	0.997
2012–2013	0.881	0.876	0.86	0.884	0.856	0.888	0.869	0.867	0.878
2013–2014	1.079	1.052	1.081	1.044	1.084	1.125	1.091	1.082	1.082
2014–2015	0.924	1.329	0.953	0.98	0.951	0.987	0.964	0.914	0.927
Period	Weihai	Rizhao	Laiwu	Linyi	Dezhou	Liaocheng	Binzhou	Heze	Mean
2006–2007	0.964	0.894	1.081	1.005	1.434	0.838	1.098	0.991	1.041
2007–2008	1.027	0.825	0.885	0.983	0.883	1.047	1.021	1.146	1.019
2008–2009	0.95	1.079	0.642	0.853	1.424	0.761	0.838	0.787	0.885
2009–2010	1.197	1.105	0.919	1.035	0.556	1.031	0.971	0.977	0.989
2010–2011	0.693	0.687	0.924	0.469	0.689	0.68	0.842	0.554	0.705
2011–2012	1.013	1.01	0.928	0.926	1.025	0.954	1.038	0.888	0.993
2012–2013	1.023	0.914	0.864	0.945	1.043	0.867	0.865	0.915	0.898
2013–2014	1.137	0.947	0.861	1.017	1.004	0.984	1.002	1.081	1.042
2014–2015	0.931	0.917	0.988	0.921	0.87	0.945	0.975	0.969	0.963

Fig. 2 Malmquist index trend of water use efficiency in Shandong Province for the period 2006–2015



Dynamic analysis of water use efficiency in Shandong Province

1. Malmquist index

According to the above-mentioned theories, a dynamic analysis of water use efficiency in Shandong Province was performed using DEA-based Malmquist index method. Malmquist index (TFP) of water use efficiency of each of 17 cities in Shandong Province was obtained for the period

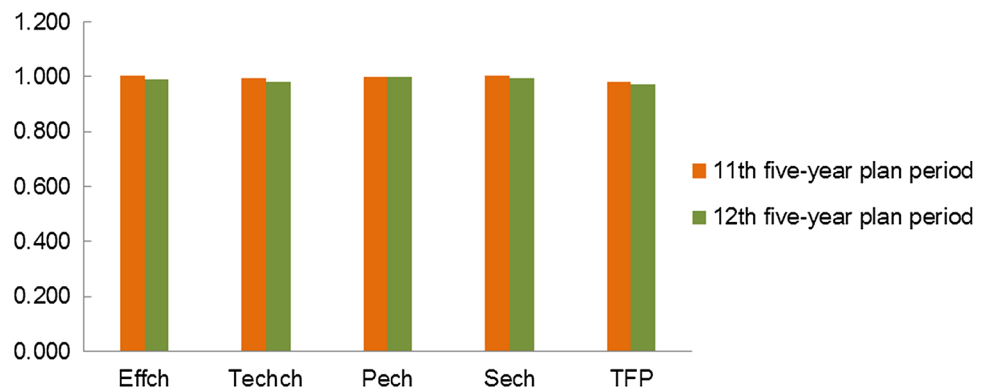
2006–2015 using the DEAP2.1 software, and the results are shown in Table 3. The trend of mean Malmquist index of water use efficiency in Shandong Province for the period 2006–2015 is shown in Fig. 2.

Table 3 shows that TFP of water use efficiency of 17 cities in Shandong Province for the period 2006–2015 ranges from 0.466 to 1.434. Additionally, as shown in Fig. 2, TFPs of 2006–2007, 2007–2008, and 2013–2014 exceed unity, implying that water use efficiency during these periods was in the positive. TFPs for the other periods are less than unity, implying that water use efficiency during these periods was in the negative.

Table 4 A summary of TFPs of 17 cities in Shandong Province during 11th and 12th Five-year Plan periods

Region	11th Five-year Plan period					12th Five-year Plan period				
	Effch	Techch	Pech	Sech	TFP	Effch	Techch	Pech	Sech	TFP
Jinan	1.011	1.000	1.000	1.011	1.011	1.000	0.974	1.000	1.000	0.974
Qingdao	1.009	1.036	1.000	1.009	1.046	1.000	1.060	1.000	1.000	1.060
Zibo	1.025	0.962	1.015	1.010	0.986	1.000	0.972	1.000	1.000	0.972
Zaozuang	1.000	0.897	1.000	1.000	0.897	1.000	0.974	1.000	1.000	0.974
Dongying	1.000	1.006	1.000	1.000	1.006	1.000	1.003	1.000	1.000	1.003
Yantai	1.032	1.038	1.000	1.032	1.071	1.000	1.020	1.000	1.000	1.020
Weifang	1.000	1.022	1.000	1.000	1.022	1.005	0.972	1.004	1.001	0.977
Jining	1.000	0.959	1.000	1.000	0.959	0.974	0.949	0.978	0.996	0.924
Tai'an	1.000	1.027	1.000	1.000	1.027	1.023	0.946	1.015	1.008	0.968
Weihai	1.000	1.030	1.000	1.000	1.030	1.000	1.023	1.000	1.000	1.023
Rizhao	1.000	0.968	1.000	1.000	0.968	0.988	0.958	0.997	0.991	0.946
Laiwu	0.996	0.870	1.000	0.996	0.866	0.944	0.963	1.000	0.944	0.909
Linyi	1.000	0.966	1.000	1.000	0.966	1.001	0.951	1.000	1.001	0.952
Dezhou	1.000	1.001	1.000	1.000	1.001	1.000	0.983	1.000	1.000	0.983
Liaocheng	1.000	0.911	1.000	1.000	0.911	0.975	0.961	0.978	0.997	0.937
Binzhou	1.006	0.972	1.000	1.006	0.977	0.969	0.998	1.000	0.969	0.968
Heze	1.000	0.967	1.000	1.000	0.967	1.000	0.961	1.000	1.000	0.961
Mean	1.005	0.997	1.001	1.004	0.982	0.993	0.980	0.998	0.994	0.973

Fig. 3 Comparison diagram of TFP index summary between 11th and 12th Five-year Plan periods



2. Malmquist index summary

Based on Malmquist index approach, this paper analyzed TFP trend of water use efficiency of 17 cities in Shandong Province. TFP trend was decomposed into Effch and Techch, and Effch was further decomposed into a pure technical efficiency-change component (Pech) and a scale efficiency-change component (Sech), i.e., $TFP = Effch \times Techch = Techch \times (Pech \times Sech)$.

A summary of TFP of water use efficiency of each of 17 cities in Shandong Province during the 11th Five-year Plan period (i.e., 2006–2010) and the 12th Five-year Plan period (i.e., 2011–2015) is given in Table 4.

The comparison diagram of TFP index summary (i.e., Effch, Techch, Pech, and Sech) between the 11th and 12th Five-year Plan period is shown in Fig. 3. And the spatial

distribution of TFPs of 17 cities during the 11th and 12th Five-year Plan periods is shown in Fig. 4.

Table 4 shows that the mean TFPs of water use efficiency in Shandong Province were all less than unity during the 11th and 12th Five-year Plan periods. Further, the Effch, Pech, and Sech of water use efficiency in Shandong Province were all larger than unity during the 11th Five-year Plan period, and Effch, Techch, Sech, and Pech were all less than unity during the 11th and 12th Five-year Plan period.

As shown in Fig. 3, the mean TFP index summary of water use efficiency in Shandong Province during the 12th Five-year Plan period is all less than 11th Five-year Plan period. The decreasing ratio of Effch, Techch, Pech, Sech, and TFP is 1.19%, 1.71%, 0.30%, 1.00%, and 0.92%, respectively.

As shown in Fig. 4, by comparing TFP_1 and TFP_2 , the cities in Shandong Province can be divided into four categories.

Fig. 4 Spatial distribution of TFP of 17 cities during the 11th and 12th Five-year Plan periods. *Note:* TFP1 and TFP2 refer to the results from the 11th and 12th Five-year Plan period, respectively

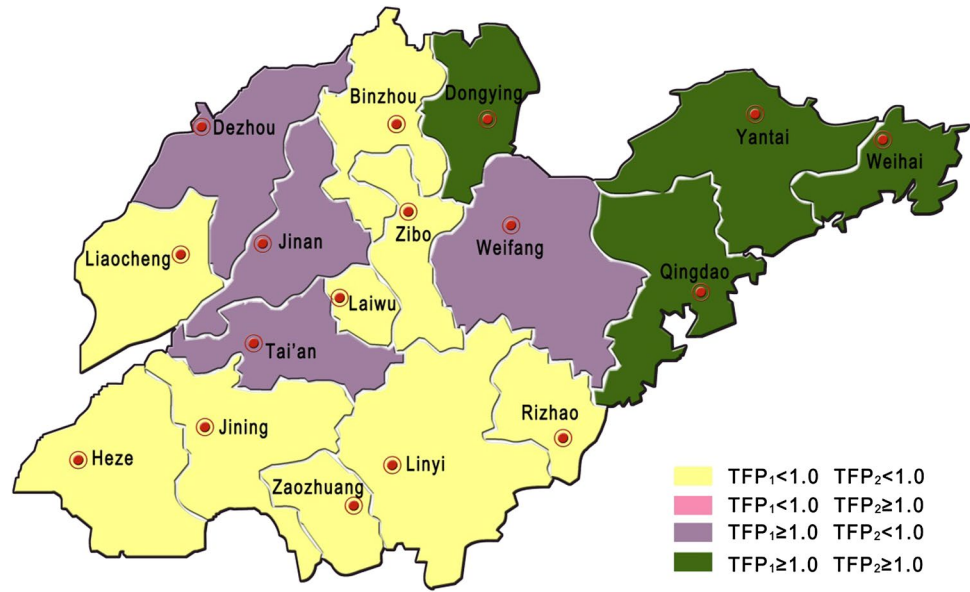


Table 5 Influence factors of water use efficiency of 17 cities during the 12th Five-year Plan period

Region	Techch	①	Pech	②	③	④	Sech	⑤
Jinan	0.974	0.994	1.000	358.536	14.760	2.164	1.000	10.411
Qingdao	1.060	0.774	1.000	108.196	6.072	1.894	1.000	17.432
Zibo	0.972	0.722	1.000	395.950	14.164	1.712	1.000	17.799
Zaozhuang	0.974	0.238	1.000	189.952	10.984	2.943	1.000	16.869
Dongying	1.003	0.806	1.000	717.184	9.170	2.118	1.000	20.292
Yantai	1.020	0.598	1.000	277.148	4.408	2.617	1.000	11.265
Weifang	0.972	0.448	1.004	176.000	13.912	4.088	1.001	18.377
Jining	0.949	0.250	0.978	401.940	15.876	4.046	0.996	17.643
Tai'an	0.946	0.374	1.015	263.684	14.136	4.227	1.008	15.694
Weihai	1.023	0.646	1.000	222.184	5.822	1.221	1.000	17.707
Rizhao	0.958	0.144	0.997	295.678	18.624	3.229	0.991	9.119
Laiwu	0.963	0.378	1.000	510.412	31.778	2.772	0.944	14.195
Linyi	0.951	0.180	1.000	256.678	15.846	4.779	1.001	18.060
Dezhou	0.983	0.216	1.000	241.306	13.032	6.825	1.000	15.312
Liaocheng	0.961	0.180	0.978	277.580	17.012	6.481	0.997	18.830
Binzhou	0.998	0.404	1.000	423.396	11.084	6.780	0.969	16.479
Heze	0.961	0.094	1.000	316.648	15.544	7.249	1.000	17.689
Mean	0.980	0.438	0.998	286.086	11.934	3.431	0.994	15.599

① R&D staff ratio (%); ② water consumption per unit of grain production (m³/t); ③ water consumption per unit of industrial added value (m³/ten thousand yuan); ④ COD emission per unit GDP (kg/ten thousand yuan); ⑤ annual growth rate of investment in fixed assets of the whole society (%)

TFP₁ and TFP₂ are greater than unity in Dongying, Yantai, Weihai, and Qingdao, TFP₁ is greater than unity and TFP₂ is less than unity in Dezhou, Jinan, Tai'an, and Weifang, but there are no cities whose TFP₁ is less than unity and whose TFP₂ exceeds unity. In the others cities, TFP₁ and TFP₂ are both less than unity.

3. Analysis of influence factors of water use efficiency

The factors that influence water use efficiency were received from a combination of input–output indexes. R&D staff ratio and proportion of R&D expenditure to GDP can explain technical change (Techch), the water consumption per unit

of grain production and water consumption per unit of industrial added value explain pure technical efficiency change (Pech), and the annual growth rate of investment in fixed assets of the whole society explain scale efficiency change (Sech). The factors that influenced water use efficiency of 17 cities in Shandong Province during 12th Five-year Plan period are shown in Table 5.

Table 5 shows that the results of TFP summary are related to the factors that influence water use efficiency. The R&D staff ratio of cities with a Techch that is less than unity, such as Zaozhuang, Jining, Tai'an, Rizhao, Laiwu, Linyi, Dezhou, Liaocheng, Binzhou, and Heze, is lower than the province's average. In cities with a Pech that is less than unity, the water consumption per unit of grain production of Jining and Rizhao, the water consumption per unit of industrial added value of Jining, Rizhao, and Liaocheng, and COD emission per unit GDP of Jining and Liaocheng are greater than the province's average. The annual growth rate of investment in fixed assets of the whole society of the cities with a Sech that is less than unity is lower than the province's average: examples are Jining, Rizhao, Laiwu, Liaocheng, and Binzhou.

Conclusion and suggestion

From the perspective of input and output, this paper has selected agricultural water consumption, industrial water consumption, domestic water consumption, total COD discharge quantity, investment in fixed assets of the whole society, and labor of the whole society as input indicators, and GDP and grain output as output indicators. The water use efficiency in Shandong Province for the period 2006–2015 was measured by using SE-DEA model, and dynamic analyses were performed by using Malmquist index based on DEA during the 11th and 12th Five-year Plan periods. The results show that, in general, during the period studied, the water use efficiency of the 17 cities in Shandong Province experiences deteriorations with super-efficiency scores that fluctuate between 0.466 and 1.434. However, there is significant divergence among cities, and the TFPs of the water use efficiency in Shandong Province during the 12th Five-year Plan period are all less than those during the 11th Five-year Plan period.

The factors that influence water use efficiency were analyzed based on Table 5, and suggestions for promoting water use efficiency in Shandong Province can be made. Firstly, the R&D staff ratio is a key influencing factor for Zaozhuang, Jining, Tai'an, Rizhao, Laiwu, Linyi, Dezhou, Liaocheng, Binzhou, and Heze, so the technical change efficiency (Techch) of these cities could be promoted by increasing the number of R&D personnel. Secondly, the water consumption per unit of grain production is the key influencing factor for Jining and Rizhao, the water consumption per unit of added value

to industry is a key influencing factor for Jining, Rizhao, and Liaocheng, and the COD emission per unit of GDP is a key influencing factor for Jining and Liaocheng. So, the pure technical efficiency change (Pech) could be improved in two respects. One is to promote water efficiency in agriculture by developing agricultural science and technology and spreading water-saving technology in agriculture. The other is to reduce COD emissions, increase the reuse rate of water in industry and promote water use efficiency in industry by eliminating backward industries, reducing high water consumption, promoting the rapid development of new industrial technologies, and implementing cleaner production. Finally, the annual growth rate of investment in fixed assets of the whole society is a key influencing factor in the scale efficiency change (Sech) of Jining, Rizhao, Laiwu, Liaocheng, and Binzhou, which could be improved by increasing the investment in the total amount of fixed assets.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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