Evaluate the efficiency of water conservancy investment in Shaanxi Province based on super-efficient DEA and malmquist index

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Abstract. Water conservancy construction is an important infrastructure related to national economic and social development, and effective water conservancy investment is the premise guarantee for water conservancy reform. Therefore, it is necessary to study the efficiency of water conservancy investment. The efficiency of water conservancy investment in Shaanxi Province is evaluated by the super-efficiency DEA model and the Malmquist index. The results show that the comprehensive efficiency of water conservancy investment in most regions of Shaanxi Province increased steadily from 2012 to 2017, and pure technical efficiency is the main reason that hinders the further improvement of the efficiency of water investment in various regions. Therefore, it is necessary to strengthen technological innovation, optimize organizational structure, continuously adopt advanced technology, and expand the scale of water conservancy construction in order to attain the maximum value of investment.

1. Introduction
As the foundation of national economic and social development, water conservancy needs a large amount of economic input. Over the years, Shaanxi’s water conservancy investment has continued to increase. In 2017, the water investment in Shaanxi province had reached 27.84 billion yuan, an increase of 46.55% compared with 2012. The proportion of total water investment in the province’s GDP reached 1.27%. In the past ten years, although the province’s water conservancy investment has made remarkable achievements, compared with the needs of economic and social development, water investment management is faced with severe challenges. There are still some outstanding problems and weakness in the implementation and use efficiency of funds. Therefore, it is very necessary to study the efficiency of water conservancy investment in Shaanxi Province and get to the bottom of the matter. Besides this will help better define the relationship between the costs and benefits, find key factors that affect the efficiency of water investment, provide direction for future investment decisions, and promote the development of water conservancy construction in Shaanxi Province towards a more stable and healthy direction.

This paper intends to use the super-efficiency DEA (Data Envelopment Analysis) model to evaluate the water investment efficiency of 10 regions including Xi’an City, Tongchuan City, Baoji
City, Xianyang City, Weinan City, Yan'an City, Hanzhong City, Yulin City, Ankang City and Shangluo City in Shaanxi Province from 2012 to 2017, then calculate the Malmquist index on the investment efficiency of water conservancy construction in each region from 2012 to 2017, and obtain the changes in the technology and scale efficiency of various regions, in order to identify the main factors affecting the efficiency of investment, provide new ideas for future development work.

2. Literature review
Research on water conservancy investment and its efficiency has always been a hot topic of discussion. Building a perfect indicator system is the basis for conducting research on the efficiency of water conservancy investment. Cao and Yuan [1] used the completion amount of water investment as the input indicator, water supply, grain yield, effective irrigated region and population protection of dike project as the output indicators when analyzing the efficiency of water investment in the Yangtze river economic belt. Initially DEA model is the preferred method for people to study the efficiency of investment. He [2] based on the input and output data of farmland water conservancy construction in 13 major grain producing regions in China in 2011, used DEA to measure the comprehensive efficiency and scale efficiency of farmland water conservancy investment in various regions, and found that technical efficiency and scale efficiency presented unbalanced development. Later, some scholars found that the DEA model was deficient in contrasting effective decision unit, and there are also defects in further analysis for production. Therefore, super-efficiency DEA and dynamic Malmquist index model have gradually been accepted by many scholars. Wang and Yuan [3] used super-efficiency DEA and Malmquist index model to analyze the change trend of water conservancy investment efficiency during the "Eleventh Five-Year Plan" period. He found that the low technology efficiency of water conservancy investment was mainly due to the lower scale efficiency, and the efficiency of water conservancy investment in the western region was better than that in the eastern and central regions. Hua, Qi and Ma [4] used super-efficiency DEA and Malmquist index model to analyze the investment efficiency and changes of water conservancy construction in 31 regions in China from 2007 to 2012. The results showed that the investment efficiency of water conservancy construction in different regions is quite different and generally showed a downward trend, showing a “west-east-middle” pattern. Thus, it can be seen that the super-efficiency DEA and Malmquist index are increasingly becoming effective methods for analyzing the efficiency of water investment.

Shaanxi is an important location in exploitation of west region and plays a role as a bridge between east and west of China. However, as the infrastructure for the development of the western region, the construction of water conservancy projects is still lacking in the research of investment efficiency. In order to make up for this vacancy, better implement the policy of western development, and provide suggestions for the development of water resources and ecological environment in Shaanxi Province. Therefore the research and analysis of this paper is very important.

3. Research methods and data description

3.1. Research method
- Super-efficiency DEA

In 1993, Andersen and Petersen proposed the super-efficient DEA model based on the CCR (A. Charnes & W. W. Cooper & E. Rhodes) model [5]. Overcoming the shortcomings of the traditional DEA model, so that the decision units that reach DEA effective can also be compared. Moreover, for the invalid decision-making unit, the comprehensive efficiency is the same as the traditional DEA model. The efficiency value of the effective unit due to the backward movement of its production front surface is greater than the measured value of the conventional DEA model, that is, greater than 1. The mathematical expression of the super-efficient DEA model is shown in equations (1) and (2).
\[ \min \left[ \theta - \varepsilon \left( \sum_{i=1}^{m} S_{i}^{-} + \sum_{r=1}^{p} S_{r}^{+} \right) \right] \]  

(1)

\[
\begin{align*}
\sum_{j=1, j \neq k}^{n} & \lambda_j x_{ij} + S_i^{-} = \Theta x_0, i = 1, 2 \ldots m, \lambda_j \geq 0, j = 1, 2 \ldots n \\
\sum_{j=1, j \neq k}^{n} & \lambda_j x_{rj} - S_i^{+} = y_0, r = 1, 2 \ldots p, S_i^{-} \geq 0, S_i^{+} \geq 0
\end{align*}
\]

(2)

where \( \Theta \) is the effective value of the decision unit; \( S_i^{-} \), \( S_i^{+} \) is slack variable for input and output; \( \lambda_j \) is DMU (Decision Making Unit) coefficient for decision unit; \( x_{ij} \), \( y_{ij} \) is input and output elements. When \( \theta < 1 \), it indicates the decision unit DMU is not a valid DEA, \( \theta > 1 \), it indicates DMU is a valid DEA, and the larger the value of \( \theta \), the higher the efficiency value. The Malmquist index can be broken down into technical changes (Techch) and technical efficiency changes (Tech).

- Malmquist index

The Malmquist index was first proposed by Malmquist in 1953 and then applied to production analysis by Fare et al. The Malmquist index is used to indicate how fast the productivity of each decision unit changes from period \( t \) to \( t+1 \). The Malmquist index can be broken down into technical changes (Techch) and technical efficiency changes (Tech). Among them, the change of technical efficiency can be further decomposed into pure technical efficiency change (Pech) and scale efficiency change (Sech). The expression of the Malmquist productivity index is shown in equation (3).

\[
m_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left( \frac{d_{t}^{0}(x_{t+1}, y_{t+1})}{d_{t}^{0}(x_{t}, y_{t})} \times \frac{d_{t+1}^{0}(x_{t+1}, y_{t+1})}{d_{t+1}^{0}(x_{t}, y_{t})} \right)^{\frac{1}{2}}
\]

(3)

\[
= \text{tech} \times \text{techch}
\]

The investment of water conservancy projects in the period \( t \) and \( t+1 \) is represented by \( x_t, x_{t+1}, y_t, y_{t+1} \) indicates the output of the \( t \) and \( t+1 \) period, \( d_{t}^{0}, d_{t+1}^{0} \) is the distance function (technical level) in the period \( t \) and period \( t+1 \). When the Malmquist index value \( tfpch \) (Total Factor Productivity Change) \( = m_0(x_t, y_t, x_{t+1}, y_{t+1}) = 1 \), the productivity is unchanged; \( m_0(x_t, y_t, x_{t+1}, y_{t+1}) > 1 \), indicating that the total factor efficiency is improved; \( m_0(x_t, y_t, x_{t+1}, y_{t+1}) < 1 \), it indicates that the efficiency decreased. Decompose the formula (3), and the result is shown in the formula (4): Where tech is a change in technical efficiency; techch is a technical changes. Technical changes (Tech) can be further decomposed into the pure technical efficiency change (Pech) and scale efficiency change (Sech). The result is shown in equation (5):

\[
tech = \frac{d_{t+1}^{0}(x_{t+1}, y_{t+1})}{d_{t}^{0}(x_{t}, y_{t})}
\]

(5)
\[ = \text{sech} \times \text{pech} \]

In summary, \( m_0(x_t, y_t, x_{t+1}, y_{t+1}) = \text{tech} \times \text{tech} \) or \( m_0(x_t, y_t, x_{t+1}, y_{t+1}) = \text{sech} \times \text{pech} \times \text{tech} \), total factor productivity is further broken down into scale efficiency change, pure technical efficiency change and technical changes. When the index changes more than 1, it indicates that the index promotes the improvement of productivity; on the contrary, when the index is less than 1 indicates that it hinders the productivity improvement.

### 3.2. Indicator selection and data sources

Due to the limitations of the data acquisition and collection, 10 cities including Xi'an City, Tongchuan City, Baoji City, Xianyang City, Weinan City, Yan'an City, Hanzhong City, Yulin City, Ankang City and Shangluo City are selected. This paper uses these data to measure and analyze water investment efficiency. The sample involves cities in southern Shaanxi, Guanzhong and northern Shaanxi. Therefore, it is representative and can reflect the overall situation of water investment in Shaanxi Province to a certain extent. The water conservancy investment evaluation index system as shown in table 1, all of the data from the "Shaanxi Statistical Yearbook".

| Indicator type | Indicator name |
|----------------|----------------|
| Input indicator | Water conservancy construction investment (million yuan) |
| Output indicator | Total water supply (10,000 cubic meters) |
|                  | Effective irrigated area (thousand hectares) |
|                  | Newly added area of water and soil conservation (thousand hectares) |
|                  | Newly added standard length of embankment (km) |
|                  | Newly added installed capacity of rural hydropower (kw) |

### 3.3. Calculation results and analysis

![Figure 1. Average Super-efficiency value of water conservancy investment in each region.](image)

In order to analyze the input and output efficiency of water conservancy investment in various regions of Shaanxi Province more comprehensively and dynamically, this paper uses EMS1.3 (efficiency measurement system) software to calculate the super-efficiency value of water conservancy investment in each region during 2012-2017. According to figure 1, it can be found that Shangluo City has the highest efficiency of water conservancy investment, the average value of the past 6 years has
reached 2.069. And Hanzhong City is second, Yan'an City is relatively low only 0.665. The super-efficiency values of Weinan City, Hanzhong City and Shangluo City can reach 1 each year. The super-efficiency value of Shangluo City remains above 1.31 per year. In contrast, the efficiency of water conservancy investment in Xi'an, Xianyang and Yan'an City needs to be improved. As can be seen, the regions with improved efficiency include Xi'an, Baoji City, Xianyang City and Yulin City. Tongchuan City, Weinan City, Yan'an City, Hanzhong City, Ankang City and Shangluo City are reduced. Among them, the super-efficiency of Xi'an city increases the fastest, with an increase of 1.244 compared with 2012.

The efficiency of water conservancy investment in Xi'an has risen sharply in 2017, and the super-efficiency value has reached 1.828. These changes have been linked to the increase in water conservancy investment in Xi'an and a series of remarkable results. In 2017, Xi'an Water Conservancy Construction Investment reached 5.639 billion, an increase of 8.12% compared with 2016. Xi'an City has continuously promoted the comprehensive management project of the Weihe River, accelerated the ecological restoration project of the water system, implemented the rural drinking water safety project, and strengthened the construction of farmland water conservancy projects, which made the water construction of Xi'an reach a new stage of development. The super-efficient value of water conservancy investment in Yan'an City is low, mainly because Yan'an is located in the Loess Plateau and lacks water resources. It is not only a resource-deficient area, but also an area with engineering water shortage. In addition, water resources are unevenly distributed in time and space. Unbalanced supply and demand of resources make water investment less effective, resulting in lower returns on water investment.

Table 2. Super-efficiency value of water conservancy investment in various regions of Shaanxi Province from 2012 to 2017.

| Region | Years | Mean |
|--------|-------|------|
|        | 2017  | 2016 | 2015 | 2014 | 2013 | 2012 |
| Xi'an  | 1.828 | 0.378 | 0.504 | 0.633 | 0.747 | 0.584 | 0.779 |
| Tongchuan | 0.753 | 0.866 | 0.630 | 1.482 | 1.439 | 1.133 | 1.050 |
| Baoji   | 1.107 | 1.156 | 0.761 | 1.495 | 0.895 | 0.781 | 1.033 |
| Xianyang| 1.152 | 0.807 | 0.969 | 0.897 | 0.955 | 1.061 | 0.973 |
| Weinan  | 1.002 | 1.309 | 1.121 | 1.183 | 1.239 | 1.315 | 1.195 |
| Yan'an  | 0.444 | 0.559 | 0.599 | 0.696 | 0.831 | 0.859 | 0.665 |
| Hanzhong| 1.251 | 2.079 | 1.558 | 1.430 | 1.733 | 1.656 | 1.618 |
| Yulin   | 1.435 | 1.218 | 1.483 | 0.778 | 0.705 | 0.575 | 1.032 |
| Ankang  | 1.220 | 0.888 | 1.105 | 1.151 | 1.450 | 1.672 | 1.248 |
| Shangluo| 1.319 | 1.918 | 3.108 | 2.804 | 1.644 | 1.622 | 2.069 |

Shaanxi Province can be divided into three parts: southern Shaanxi, Guanzhong and northern Shaanxi. Among them, southern Shaanxi includes Yulin City and Yan'an City. Guanzhong includes Xi'an, Baoji, Xianyang, Tongchuan and Weinan, northern Shaanxi includes Shangluo, Ankang, and Hanzhong. As can be seen from Table 2, the average investment efficiency of northern Shaanxi is 0.849, Guanzhong is 1.006, and southern Shaanxi is 1.645. It can be seen that the investment efficiency shows: southern Shaanxi > Guanzhong > northern Shaanxi. The main reason for this phenomenon is the abundant water resources in southern Shaanxi, the water conservation of projects to divert water from the south to the north, comprehensive rectification of the Han River and other projects carried out, greatly promoting the development of water conservancy construction in southern Shaanxi. In contrast, the development of northern Shaanxi is slow.

Table 3 is the arithmetic mean of the Malmquist index and its decomposition results calculated by Deap2.1 (data envelopment analysis (calculation) program) software for the efficiency of water conservancy investment in 2016-2017. In the table, $effch$ represents technical efficiency change, $techch$
represents technological progress, \( pech \) represents pure technical efficiency change, \( sech \) represents scale efficiency change and \( tfpch \) represents Malmquist index. The Malmquist productivity index greater than 1 indicates an upward trend in performance levels, and the value less than 1 indicates a decrease in performance levels compared to the beginning of the year. The rate of change in technology, the rate of change in pure technical efficiency and the rate of change in scale efficiency represent the institutional changes, capital allocation, economies of scale and other factors affect the level of performance. When the decomposition index is greater than 1 this year, indicating that the indicator has a positive effect on the improvement of performance level. On the contrary, it hinders the improvement of the performance in water conservancy investment.

### Table 3. Average Malmquist index and its decomposition from 2012 to 2017 in each region.

| Region   | \( Effch \) | \( Techch \) | \( Pech \) | \( Sech \) | \( Tfph \) |
|----------|-------------|--------------|------------|------------|------------|
| Xi'an    | 0.937       | 1.082        | 1.000      | 0.937      | 1.014      |
| Tongchuan| 1.059       | 1.013        | 1.000      | 1.059      | 1.072      |
| Baoji    | 0.962       | 1.030        | 1.000      | 0.962      | 0.991      |
| Xianyang | 1.000       | 0.983        | 1.000      | 1.000      | 0.983      |
| Weinan   | 1.000       | 1.238        | 1.000      | 1.000      | 1.238      |
| Yan'an   | 1.188       | 0.968        | 1.000      | 1.188      | 1.150      |
| Hanzhong | 1.162       | 1.085        | 1.000      | 1.162      | 1.261      |
| Yulin    | 0.997       | 0.954        | 1.000      | 0.997      | 0.952      |
| Ankang   | 0.991       | 0.968        | 0.992      | 0.999      | 0.960      |
| Shangluo | 1.000       | 1.004        | 1.000      | 1.000      | 1.004      |
| Mean     | 1.027       | 1.030        | 0.999      | 1.027      | 1.057      |

It can be seen from table 3 that the productivity index of most regions is greater than 1, and the average annual growth rate during the period from 2012 to 2017 is 5.7%, indicating that the overall situation of water conservancy investment in Shaanxi province is better. From the perspective of each region, the productivity index of Hanzhong City has reached 1.261, Weinan ranks second. The productivity indexes of Baoji City, Xianyang City, Yulin City and Ankang City are all below 1, indicating that the total factor efficiency of water conservancy investment in these areas needs to be improved. The average technical efficiency is 1.027, and the average value of technological progress is 1.03. It shows that the increase in total factor productivity is mainly due to technological progress. The technical efficiency of Tongchuan City, Yan'an City and Hanzhong City increased by 5.9%, 18.8% and 16.2% respectively, indicating that the promotion and application of water conservancy technology in these areas is more mature, which makes the technical efficiency higher. In contrast, the technical efficiency of Xi'an City, Baoji City, Yulin City and Ankang City needs to be improved. Overall, except for Xianyang City, Yan'an City, Yulin City, and Ankang City, the technological progress values are all greater than 1, indicating that all regions are paying more and more attention to the input and utilization of scientific technology.

For further analysis, the technical efficiency is decomposed into pure technical efficiency and scale efficiency. The scale of Xi'an City, Baoji City, Yulin City and Ankang City shows a downward trend, which is 9%, 6.5%, 3% and 2.8% lower than the average. The scale efficiency in Tongchuan City, Yan'an City and Hanzhong City are 1.059, 1.188, and 1.162 respectively, and the scale efficiency increased by 5.9%, 18.8%, and 16.2%, indicating that water investment in these areas has already reached a certain scale. The scale efficiency of Xianyang City, Weinan City and Shangluo City is 1, indicating that the scale efficiency has neither increased nor decreased. Regarding the pure technical efficiency, except for the decline in Ankang City, other regions remain unchanged. It can be seen that the main reason for hindering the further improvement of technical efficiency is that the pure technology efficiency is not efficient enough. Therefore, while expanding the scale of water conservancy projects, all regions should focus on improving the management level of water
conservancy investment.

4. Conclusion
Through this research and analysis described above, the following revelations are obtained:

- By rationally adjusting the investment structure and establishing a stable growth mechanism for water conservancy. A reasonable investment structure and correct planning are the prerequisites for improving the investment efficiency of water conservancy construction. It is also the basis for guiding and standardizing the construction of water conservancy projects. At the same time, strengthen coordination among departments and unified management of water resources.

- Actively introduce, research, develop and popularize new technologies, showing the guiding role of advanced science and technology in the development of productivity. Developing advanced water-saving irrigation technologies can greatly improve rural water conservancy development and economic benefit, such as drip irrigation and sprinkler irrigation, let us see the hope that technological progress brings to the development of water conservancy. Therefore, it is necessary to increase investment in scientific research, enhance the ability of independent innovation, learn advanced water conservancy technology at home and abroad, cultivate cutting-edge talents, and promote development with technological innovation.

- Continuously increase supervision. Water conservancy construction investment is applied to water conservancy infrastructure construction, water source protection, groundwater development and other aspects. In order to meet the requirements of policy implementation and capital availability, the necessary regulatory measures are indispensable.

- Enrich the reward and punishment system. Establishing reward mechanism in achievements of water conservancy science and technology, assessment mechanism of scientific research work, constraint discipline of scientific research work, etc. Fully mobilizing the enthusiasm of water conservancy researchers and improving the professionalism of employees. Achieving a win-win goal of rapid advancement in water conservancy technology and outstanding achievements in water conservancy construction.

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References
[1] Cao W Y and Yuan R H 2018 Analysis on the efficiency of water conservancy investment in the Yangtze River economic belt J. Wuhan Univ. Technol. (Inform. Manag. Eng. Ed.) 40 450-4
[2] He P J 2014 Analysis on investment efficiency of farmland water conservancy infrastructure in main grain producing regions Grain Sci. Technol. Econ. 39 9-11+42
[3] Wang S and Yuan R H2014Analysis of water investment efficiency based on Malmquist index J. Econ. Water Resour. 32 9-12+75
[4] Hua J, Qi Z G and Ma Y L2015Research on investment efficiency of China’s water conservancy construction based on provincial (Panel) data J. Econ. Water Resour. 33 1-5+14+75
[5] Yuan X L, Zhang B S and Zhang X N 2008 Evolution characters of China’s cities based on the super-efficient DEA Urban Dev. Res. 15 102-7
[6] Are R S and Lovell C 1994 Production Frontiers (Cambridge: Cambridge University Press) pp 56-60