Analysis of water use efficiency and influencing factors of agricultural total factors in Beijing-Tianjin-Hebei region

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Abstract. In this study, super efficiency SBM-DEA model was used to estimate the total water use efficiency of agricultural factors in the Beijing-Tianjin-Hebei region from 2000 to 2013, and on this basis, panel Tobit model was used to test the influence of natural conditions, water conservancy facilities, agricultural production conditions and social and economic conditions on the total water use efficiency of agricultural factors. The results show that although the overall water use efficiency of agriculture in Beijing-Tianjin-Hebei region is higher than the national level, there is still room for improvement. In the future, it should strengthen the protection and cooperation of agricultural water resources and water-saving technologies in the three regions. shared; The ratio of groundwater to water supply structure and the price index of agricultural production materials have a significant positive impact on the water efficiency of all-factory agriculture in Beijing-Tianjin-Hebei. The reservoir capacity, animal husbandry and fishery account for the proportion of total value of agricultural output the per capita cultivated land area, and the per capita net income of rural households. The quality of rural labor has a significant negative impact on the water efficiency of all-factory agriculture in Beijing, Tianjin and Hebei.

Keywords: Beijing-Tianjin-Hebei region; total water use efficiency of agricultural factors; Influential factors.

1. Introduction
The Beijing-Tianjin-Hebei region accounts for less than 2.3 percent of China's land area and 0.7 percent of its water resources[1]."Water crisis" has become the primary bottleneck restricting the coordinated development of Beijing-Tianjin-Hebei region[2]. As the proportion of agricultural water reducing year by year, the scarcity of water resources and value increasingly prominent, more and more experts and scholars began to consider how to implement the least under the established agricultural output water into, in the field of agricultural economics, research on water efficiency in agriculture mainly from two aspects: one is based on farmer data of micro water efficiency in agriculture research[3]; The second is wue research based on national or provincial agricultural production data[4].

This study constructs the super-efficient SBM-DEA model, integrates water resources into economic variables from the perspective of economic research, measures the agricultural water use efficiency in the Beijing-Tianjin-Hebei region from 2000 to 2013 under the framework of total factor production, and tests the natural endowment with the panel Tobit model. The impact of factors such as
water conservancy facilities, human capital and agricultural scale on agricultural water use efficiency, and identify the direction and countermeasures for improving the water efficiency of agricultural all-factory in the Beijing-Tianjin-Hebei region, with a view to further strengthening agricultural water management and upgrading agricultural water use in the Beijing-Tianjin-Hebei region. Efficiency provides a reference basis to help alleviate the main contradiction between severe water shortage and extensive water use in the Beijing-Tianjin-Hebei region.

2. Determination of water use efficiency of agricultural all-element in Beijing-Tianjin-Hebei region

2.1. Model setting and analysis methods
For panel data. DEA is a production frontier for each cycle, suitable for small sample macro data estimation. The data of this study are derived from macro design, focusing on samples from Beijing, Tianjin and Hebei, suitable for DEA [5].

Different from the traditional DEA model, the super-efficiency DEA further optimizes the efficiency evaluation method, and eliminates the constraint with the efficiency value \( \leq 1 \), so that the decision unit with the original efficiency value equal to 1 can be distinguished. Considering that the agricultural water used in this study is a basic input factor for agricultural production, the efficiency of agricultural water efficiency is evaluated by using the super-efficient SBM-DEA model based on slack variables and capable of ranking relatively effective decision-making units [6].

The super-efficient SBM-DEA model can be expressed as equation (1)

\[
\min \rho_{SE} = \frac{1 - \sum_{i=1}^{m} \frac{s_i^/-x_{ik}}{\bar{x}_{ik}}}{\sum_{r=1}^{n} \frac{s_r^+/y_{rk}}{y_{rk}}}
\]

s.t.

\[
\left\{ \begin{array}{l}
\sum_{j=1, j \neq k}^{n} x_{ij} \lambda_j - s_i^- \leq x_{ik} \\
\sum_{j=1, j \neq k}^{n} y_{rj} \lambda_j + s_r^+ \leq y_{rk} \\
\lambda_i, s_i^-, s_r^+ \geq 0 \\
i = 1, 2, \ldots, m; \\
r = 1, 2, \ldots, q; \\
j = 1, 2, \ldots, n (j \neq k)
\end{array} \right.
\]

(1)

2.2. Total Factor Agricultural Water Efficiency
This study draws on the concept of total factor input efficiency proposed by Hu et al., and combines the characteristics of agricultural production to define the total agricultural water efficiency (TFAWE) as the potential agricultural water input required for the decision-making unit to achieve optimal technical efficiency (Target Agricultural Water Input, TAWI) and the actual Agricultural Water Input (AAWI) ratio, as shown in equation (2)

\[
TFAWE_{lt} = \frac{TAWI_{lt}}{AAWI_{lt}} = \frac{AAWI_{lt} - EAWI_{lt}}{AAWI_{lt}} = 1 - \frac{EAWI_{lt}}{AAWI_{lt}}
\]

(2)

2.3. Variable selection and data processing
In this study, Beijing, Tianjin, Hebei, Beijing-Tianjin-Hebei region and the whole country were selected as five decision-making units, and panel data of five units from 2000 to 2013 were established. The input and output variables of the study were based on unit area data.

Specifically, in terms of variable selection, the agricultural water input involved in this study is the total input for agriculture, forestry, animal husbandry and fishery, and is converted at a constant price in 2000. Agricultural input variables include fertilizer use per hectare of planted area, total agricultural machinery power, employment in agriculture, forestry, animal husbandry and fishery, and agricultural water use.
2.4. Empirical analysis
Using the MAXDEA software, the ultra-efficient SBM-DEA with input-oriented and constant scale returns is used to measure the water efficiency of agricultural all-element in the Beijing-Tianjin-Hebei region and the whole country. The results are as follows:

It can be seen from Table 1 that the overall TFAWE in the Beijing-Tianjin-Hebei region remained at around 0.7 in 2000-2013, which was significantly higher than the national level. In terms of the Beijing-Tianjin-Hebei region, the TFAWE values in Beijing and Tianjin have been higher than the regional overall level, while the TFAWE value in Hebei has been lower than the regional overall level. Among them, Beijing's TFAWE value is higher than 1, maintaining the frontier of agricultural water, far ahead of other provinces, indicating that Beijing's agricultural water-saving technology level is higher. Tianjin's TFAWE showed a downward trend. From 2000 to 2002, Tianjin's TFAWE value was >1 and higher than that of Beijing. After 2003, Tianjin's TFAWE continued to decrease. Although it rose to 0.92 in 2010, it has been behind Beijing.

Table 1. The TFAWE of Jing-Jin-Ji area and the nation

| Year | Beijing | Tianjin | Hebei | Jing-Jin-Ji area | The nation |
|------|---------|---------|-------|------------------|------------|
| 2000 | 1.00    | 1.00    | 0.81  | 0.84             | 0.56       |
| 2001 | 1.00    | 1.00    | 0.81  | 0.83             | 0.56       |
| 2002 | 1.00    | 1.01    | 0.77  | 0.81             | 0.49       |
| 2003 | 1.04    | 0.96    | 0.89  | 0.73             | 0.47       |
| 2004 | 1.13    | 0.89    | 0.79  | 0.74             | 0.47       |
| 2005 | 1.26    | 0.80    | 0.71  | 0.74             | 0.47       |
| 2006 | 1.23    | 0.78    | 0.70  | 0.72             | 0.46       |
| 2007 | 1.24    | 0.74    | 0.70  | 0.72             | 0.46       |
| 2008 | 1.27    | 0.79    | 0.75  | 0.77             | 0.46       |
| 2009 | 1.20    | 0.78    | 0.75  | 0.75             | 0.46       |
| 2010 | 1.09    | 0.72    | 0.76  | 0.76             | 0.46       |
| 2011 | 1.13    | 0.85    | 0.75  | 0.75             | 0.44       |
| 2012 | 1.20    | 0.77    | 0.66  | 0.69             | 0.59       |
| 2013 | 1.24    | 0.70    | 0.68  | 0.70             | 0.59       |

Fig.1 Box plot of the TFAWE in Jing-Jin-Ji area and the nation

It can be seen from Figure 1 that the TFAWE variance between Beijing and Tianjin is large, indicating that the TFAWE values of these two places are unstable from 2000 to 2013, and the gap between the two years is large. Based on the previous analysis results, Beijing agriculture has been used for nearly 14 years. The efficiency of all-factor water use has increased rapidly, while the efficiency of all-factory water use in Tianjin has declined rapidly. The national TFAWE variance is small but the efficiency value is very low, indicating that the overall agricultural water efficiency in China is slow to improve, and agricultural water saving has great potential. In terms of quantile, Beijing ranks first, followed by Tianjin, followed by Beijing-Tianjin-Hebei region and Hebei. The country has the lowest quantile, with Beijing with the highest efficiency (14-year average of 1.18) than the whole country. The average level (14-year average of 0.46) is 2.5 times higher, and there is a large difference in TFAWE values.
3. Analysis of Factors Affecting Water Use Efficiency of Agricultural Total Factors in Beijing-Tianjin-Hebei Region

3.1. Selection and explanation of influence factor variables

In terms of natural conditions, this study selects three indicators of per capita water resources, annual precipitation and groundwater as a percentage of total water supply to reflect the water resources in Beijing, Tianjin and Hebei. In terms of water conservancy facilities, the total reservoirs are selected. The ratio of capacity, water-saving irrigation area and effective irrigated area is taken as two influencing variables; in terms of agricultural production status, three representative variables are selected, namely the ratio of grain and vegetable area, the ratio of animal husbandry to total agricultural output value and the per capita cultivated area. In terms of social and economic conditions, the indicators of rural labor quality, agricultural production price index and per capita net income of rural households are used to represent.

| Code | Variable and description | Data source | Effect assumptions |
|------|--------------------------|-------------|-------------------|
| LR | Per capita water resources | China Statistical Yearbook of each year | — |
| CP | Annual precipitation | China Water Resources Bulletin of each year | not sure |
| GP | Ratio of groundwater to total water supply | China Statistical Yearbook of each year | + |
| GR | Reservoir total storage capacity | China Statistical Yearbook of each year | — |
| GC | Ratio of water-saving irrigation area to effective irrigation area | China Water Resources Bulletin of each year | + |
| GP | Grain to vegetable area ratio | China Statistical Yearbook of each year | not sure |
| SF | Ratio of pasture and hay to total agricultural output value | China Statistical Yearbook of each year | — |
| CI | Average cultivated area | Beijing rural statistics in various years, Tianjin Statistical Yearbook | + |
| XL | Rural labor quality | Beijing Rural Statistical Yearbook in various years | + |
| AD | Agricultural production price index | Beijing rural statistics in various years, Tianjin Statistical Yearbook | + |
| LG | Per capita net income of rural households | China Statistical Yearbook in various years | — |

In the effect hypothesis of the influencing variables, the Zhang found that there is a negative correlation between resource endowment and resource utilization efficiency [7]. Therefore, it is assumed that the per capita water resource impact effect is negative; the annual precipitation is sufficient, which may lead to poor water conservation awareness of farmers. On the other hand, it is also conducive to reducing irrigation water, so the impact effect is uncertain; Tong and others believe that groundwater irrigation can reduce the water delivery time and water loss, and improve irrigation efficiency [8]. Therefore, it is assumed that the proportion of groundwater in the total water supply and the efficiency of agricultural water use are positive. Correlation; reservoirs as water storage facilities, their capacity expansion may change people's water use expectations, so it is assumed that the effect of reservoir capacity on water efficiency is negative; it is generally believed that the increase in water-saving irrigation area can promote the effective use of water resources, so it is assumed that the effect of the ratio of water-saving irrigated area to effective irrigated area on agricultural water use efficiency is positive; in addition, the higher the proportion of water-consuming planting, the lower the water use efficiency, due to the difficulty in water consumption of food and vegetables in the Beijing-Tianjin-Hebei region. Accurate estimation, so the direction of the impact of planting structure on agricultural water use efficiency is uncertain, while shepherding The impact of the proportion of the proportion is negative; the expansion of agricultural production may help promote water-saving irrigation facilities, farmers
with higher education level are more likely to have water-saving awareness and master water-saving technologies, and subject to cost constraints, agricultural production inputs. The increase in factor prices will stimulate producers' water-saving enthusiasm to a certain extent, but producers with higher incomes may not invest too much energy in agricultural water-saving. Therefore, the average cultivated land area, rural labor quality and agricultural production are assumed. The impact of the data price index is positive, and the effect of per capita net income of rural households is negative.

3.2. Model setting and result analysis

This paper uses the Tobit model for dealing with restricted variables to analyze the relationship between water use efficiency and influencing factors of agricultural total factors.

\[
TFAWE_{it} = \beta_0 + \beta_1 \ln(PW_{it}) + \beta_2 \ln(YW_{it}) + \beta_3 \ln(RE_{it}) + \beta_4 W_{it} + \beta_5 \ln(\text{FV}_{it}) + \beta_6 \ln(\text{PL}_{it}) + \beta_7 \ln(HR_{it}) + \beta_8 \ln(\text{PR}_{it}) + \beta_9 \ln(\text{INC}_{it}) + \varepsilon_{it}
\]

Among them, TFAWE_{it} represents the total water use efficiency of agriculture in the i-th region in the t-th year, \(\beta_0, \beta_1, ..., \beta_9\) are the parameters to be estimated, and \(\varepsilon_{it}\) is the random error. Using the STATA 14.0 to calculate the panel using the Tobit model, the results are shown in Table 3.

Both the likelihood ratio test and the Wald test of the model reject the null hypothesis, and the goodness of fit is above 99%, and the regression effect is better. The specific effects of various factors are discussed below:

1. In terms of natural conditions, the amount of water resources per capita is negatively correlated with the water use efficiency of all-factory agriculture. This is consistent with the expected direction of the previous judgment; the proportion of groundwater in the water supply structure has a significant positive effect on the water use efficiency of agricultural all-factors.

2. In terms of water conservancy facilities, the reservoir capacity has a significant negative relationship with the agricultural all-purpose water use efficiency. Although there is a positive correlation between the water-saving irrigation area and the agricultural total factor water use efficiency, it is not significant.

3. In terms of agricultural production status, the area ratio of grain and vegetables is positively related to the water use efficiency of agricultural all-factors, but it is not significant; the proportion of animal husbandry to total agricultural output value is significantly inversely related to the water use efficiency of agricultural all-factors. The direction is consistent; there is a significant negative correlation between the per capita arable land area and the agricultural all-purpose water use efficiency, contrary to the expected direction.

4. In terms of social and economic conditions, the impact of agricultural production price index and rural household per capita net income on agricultural water use efficiency is in line with the previous expectations, and there are significant positive correlations and negative correlations; however, rural labor quality and agricultural total factors There is a significant negative correlation between water use efficiency, which is inconsistent with previous expectations.

| Influential factor | Coefficient | Z value | P value |
|--------------------|-------------|---------|---------|
| LN (PW)            | -0.087      | -1.172  | 0.241   |
| LN (YH)            | 0.0351      | 0.529   | 0.742   |
| CV                 | 2.052***    | 3.291   | 0.000   |
| LN (RE)            | -0.877***   | -4.197  | 0.000   |
| WS                 | 0.0486      | 0.46    | 0.631   |
| FY                 | 0.0264      | 1.272   | 0.201   |
| SR                 | -1.407**    | -2.59   | 0.024   |
| PL                 | -4.73***    | -4.122  | 0.000   |
| HR                 | -0.313*     | -1.872  | 0.061   |
| R                  | 0.484**     | 2.021   | 0.049   |
| LN (INC)           | -0.735***   | -2.68   | 0.007   |
| Constant           | 11.50***    | 4.456   | 0.000   |
| Log Likelihood     | 44.09882    |        |         |
| Wald chi²           | 267.45***   | /       | 0.000   |

Note:* , ** and *** represent the significance at the level of 10%, 5% and 1%
4. Main conclusions and inspiration
(1) At the regional level, the overall agricultural water use efficiency of the Beijing-Tianjin-Hebei region in recent years is about 0.7, although it is significantly higher than the national average, but the current agricultural production is achieved with the output, technology and other input factors remaining unchanged. The agricultural water consumption can still be reduced by 30%, and there is room for improvement in the water use efficiency of the Beijing-Tianjin-Hebei agricultural total factor.

(2) In Beijing, Tianjin and Hebei, Beijing's agricultural water use efficiency has shown an upward trend, and it is basically in the frontier of production; although the water efficiency of all-factory agriculture in Tianjin has declined, it is still higher than the average level of Beijing-Tianjin-Hebei region; Hebei's agricultural all-purpose water use efficiency is significantly lower than that of Beijing and Tianjin, thus lowering the overall agricultural water use efficiency level in the Beijing-Tianjin-Hebei region. As the province with the most potential for water saving in the Beijing-Tianjin-Hebei region, Hebei should improve agricultural water use efficiency as soon as possible, narrow regional differences, and at the same time strengthen the cooperation and protection of agricultural water resources in the three regions, and carry out regional promotion and application of agricultural water-saving technologies.

(3) According to the research results of the Tobit model on the factors affecting the water efficiency of the total factor of agriculture in Beijing, Tianjin and Hebei, it is necessary to point out that: First, although the proportion of groundwater in the water supply structure has a significant positive impact on the water efficiency of agricultural total factors, it should still be utilized. Relevant water-saving technologies to reduce water and water loss; secondly, although the water-saving irrigation area can explain the promotion and popularization of water-saving facilities to a certain extent, it does not reflect the actual application of water-saving technologies, so the festival is being improved. At the same time, the level of water irrigation technology should pay more attention to whether farmers actually use water-saving facilities and adopt water-saving technologies in agricultural production;

(4) This study is mainly based on macro statistics. In the future, further household surveys should be conducted in the Beijing-Tianjin-Hebei region. In addition, due to the uncertainty and complexity of agricultural water prices, how to scientifically measure the effect of agricultural water price on agricultural water use efficiency in field research? What is the effect of comprehensive agricultural water price reform that the country is advancing? These issues need further study.

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