Water Resource Development and Regional Innovation Capacity of China

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1. Introduction

Water scarcity is becoming increasingly severe all over the world, especially in developing countries. Despite the unbalanced distribution of water resources, which is a key constraint on the water consumption, population growth and economic development are the main driving forces of water demand, which result in a substantial expansion of water use. While it is observed that water use, especially industrial water use, in some developed countries has experienced an increase, leveling off, and then a decrease when the economic development and income rises, the trend of which resembles the well-known environmental Kuznets curve (EKC), named as Industrial Water Use Kuznets Curve by Jia et al. (2006). However, a study launched by Chinese Academy of Sciences (2007) predicts that Chinese industrial water use will not reach the turning point until 2030.

The serious imbalance between water supply and demand jeopardizes the sustainable development, which imposes a high demand on the efficiency of water use. Thus, it is quite necessary to measure the efficiency and explore the factors that influence it. Since the core objective is to control the increase of water use in the process of the economic development, water consumption per 10,000 Yuan GDP should be taken as a major indicator to measure the efficiency of water use. However, the information that can be reflected in the single indicator is limited. As a method adapted from multi-input and multi-output production functions, data envelopment analysis (DEA) can take more factors into consideration when measuring efficiency.

With the rapid development of China, the growth in both GDP and population imposes great pressure on water use. It turns out to be very important to promote the technique revolution in water use. How is innovation showing effects on the efficiency of water use? This paper will take use of the Regional Innovation Index of 31 mainland provinces in China designed by Renmin University of China, which shows a comprehensive picture of the innovation development of each province.

Data for the index construction, water use, GDP and population, if not mentioned, are all from China S tatistical Yearbook.

2. Water Use Efficiency Analysis Based on DEA

Data envelopment analysis (DEA) is a nonparametric method in operations research and economics for the estimation of production frontiers on which the relative performance of all utilities in the sample can be compared. It assumes that there are n independent DMUj (decision making unit, j=1,2,…,n) in a production system. Each DMUj has m inputs, $X_j = (x_{1j}, x_{2j}, \dots, x_{sj})^T$, and produces s products $Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})^T$. The points on the production frontiers show the maximum output of every input composition, and thus reflect the highest technique level. In order to evaluate the efficiency of DMUs, it only needs to measure the distance of the points to the frontiers. The further the distance is, the lower the efficiency is.

This paper is based on input-oriented model based on constant return to scale (CRS):

$$\min \qquad (1)$$

$$\sum_{j=1}^{n} {}_{j}x_{ij} + s^{-} = \ x_0, i = 1,2, \ldots, m$$

$$\sum_{j=1}^{n} {}_{j}x_{rj} - s^{+} = y_0, r = 1,2, \ldots, s$$

$$s^{-}, s^{+}, \ {}_{j} \geq 0, j = 1,2, \ldots, n$$

s^{-} and s^{+} are the slacks of each DMU's input and output. According to the assumption, this model intends to reduce the input as much as possible when keeping the output constant. If it shows $^{*} = 1$, $s^{-*} = 0$ and $s^{+*} = 0$, then DMU is DEA efficient.

In this paper, we transform the Cobb-Douglas product function. We take capital, labor and water use as inputs, and GDP as output. The objective value of water use computed based on DEA is used to construct the efficiency indicator WUIR (Water Use Improved Ratio)

$$\text{WUIR} = \frac{\text{objective value} - \text{original value}}{\text{original value}}, \quad (2)$$

which represents the ratio needs to be adjusted. The value of WUIR is between 0 and 1. The higher WUIR is, the more urgent the efficiency of water use needs to improve.

WUIR of each province is computed and shown in the following map. The values are divided into four groups: 0, 0-0.3, 0.3-0.5 and 0.5-1. The higher the value is, the darker the region shows.

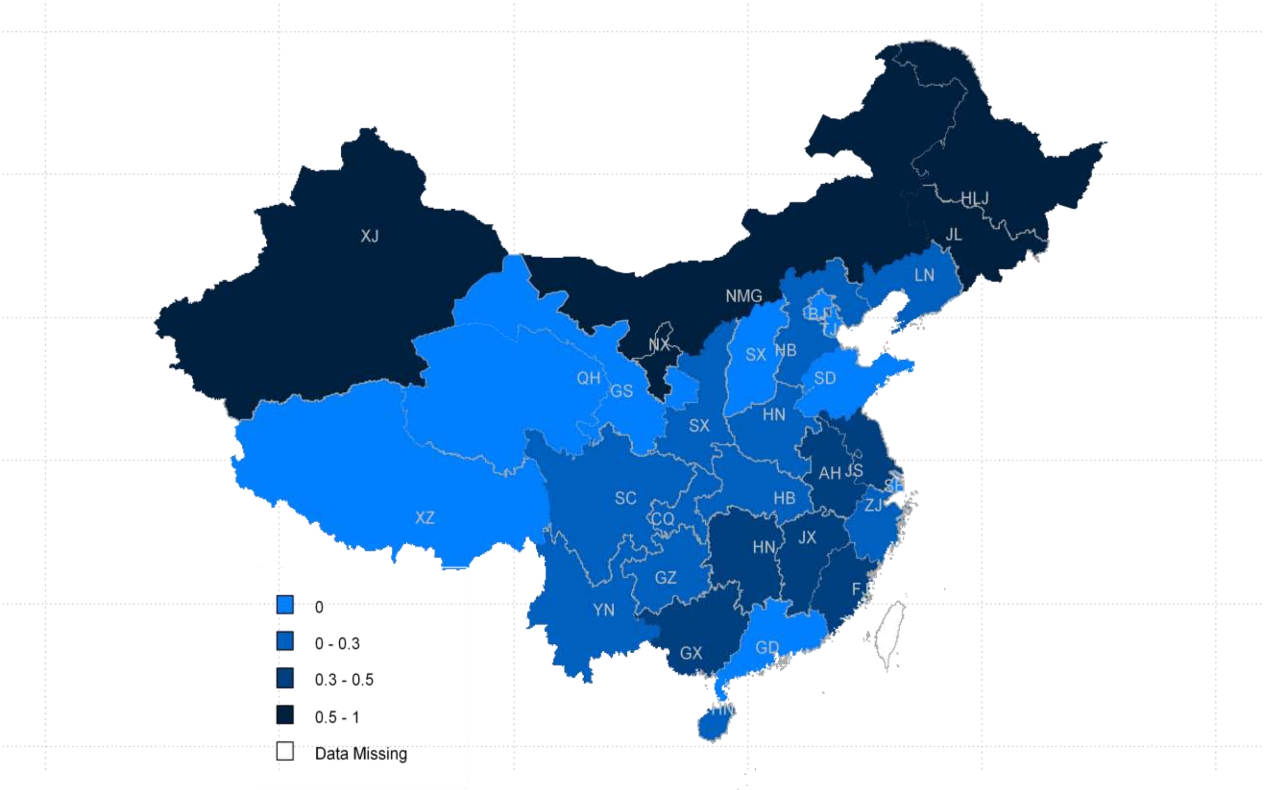


Figure 1: The Chinese map of water use efficiency based on DEA

It is clearly shown in the map that, there are as many as 9 provinces reach the objective value of water use, including Beijing, Shanghai, Guangdong, which are the most developed regions in China, and also backward western regions like Tibet, Qinghai and Gansu, whose water resources are severely scarce. Although it seems true that the more developed the region is, the more water it may consume, higher capability of innovation may play a great role in the efficiency improvement.

The regions of which WUIRs are between 0-0.3 are mainly located in the middle and south of China. Some like Zhejiang and Liaoning are littoral, and others like Guizhou and Sichuan are not so dependent on water based industries. Why doesn't the plentiful water resource cause too high water use? Higher capability of innovation may play a great role in the efficiency improvement.

Provinces in the southeast of China like Jiangsu have WUIRs as high as 0.3-0.5. Although Jiangsu's GDP is ranked as the second among all the provinces, too much dependent on water and little emphasis on innovation may result in the low efficiency of water use.

All of the regions whose WUIRs are above 0.5 are in the north of China like Heilongjiang and Inner Mongolia, which are mainly dependent on traditional manufacturing industry. Backward production technique and less efficient assembly line may cause the production scale to exceed nature sustainability.

Thus, it is necessary for us to explore and verify the factors influencing the efficiency of water use for a further step.

3. Effect of Regional Innovation Efficiency to Water Consumption

In this section, the effect of regional innovation efficiency to water consumption is rigidly examined, from pooled data to panel data, from fixed effects mean regression to fixed effects quantile regression. The main concern is water consumption per 10,000 Yuan GDP, one of indicators generally evaluation performance of local governments, and Regional Innovation Index of China is introduced as a measure of local innovation capacity.

3.1 Introduction of Regional Innovation Index of China

Regional Innovation Index of China, which is proposed by Zhao (2008) since 2000, studying the local innovation capacity of 31 mainland provinces, while Hong Kong, Macao and Taiwan are not included. The composite index takes into account totally39 indicators forming 8 pillars, almost all available indicators related to innovation in China statistics system.

Table 1: Indicators of Regional Innovation Index of China

Pillar	Indicator
1.1 Innovation Resources	1.1.1 Personnel Engaged in S&T Activities
	1.1.2 Scientists and Engineers
	1.1.3 R&D Personnel
	1.1.4 Expenditure on S&T Funds
	1.1.5 Gross Domestic Expenditure on R&D
1.2 Innovation Research	1.2.1 General Program Funds of National Natural Science Foundation
	1.2.2 Number of National Engineering Research Center
	1.2.3 Number of National Laboratories
	1.2.4 PhD Graduates

1.3 Innovation Technology	1.3.1 Invention Patent Applications 1.3.2 Total Number of Granted Patents 1.3.3 Total Number of Granted Invention Patents 1.3.4 Domestic S&T papers
	1.3.5 Transaction Number in Technical Market 1.3.6 Transaction Value in Technical Market
1.4 Innovation Value Realization	1.4.1 Added Value of High-tech Industry
	1.4.2 Exports of High-tech Products
	1.4.3 Agricultural Labor Productivity 1.4.4 Service Sector Labor Productivity
1.5 Creative Talents	1.5.1 Master Graduates
	1.5.2 Scientists' Graduate Culturing Rate 1.5.3 Rate of R&D Expenditure on Graduate Culture
1.6 Innovation Radiation	1.6.1 Transaction Value in Technical Market/ National Transaction Value
	1.6.2 Added Value of High-tech Industry/ National Value-Added of High-tech Industry 1.6.3 Added Value of High-tech Industry/ Value-Added of Industry
1.7 Continuous Innovation	1.7.1 Growth Rates of Granted Invention Patents (three year average) 1.7.2 Growth Rates of Invention Patent Applications (three year average) 1.7.3 Growth Rates of Granted Total Patents (three year average) 1.7.4 Growth Rates of Transaction Value in Technical Market (three year average)
	1.7.5 Gross Domestic Expenditure on R&D/ GDP 1.7.6 Government S&T Appropriation/ Total Government Expenditure 1.7.7 Expenditure on S&T Funds/ GDP 1.7.8 Added Value Rate of High-tech Industry
1.8 Innovation Network	1.8.1 Personnel Engaged in S&T Activities per 10,000 labor force 1.8.2 R&D Personnel per 10,000 Labor Force
	1.8.3 Expenditure on S&T Funds per Scientist and Engineer 1.8.4 Gross Domestic Expenditure on R&D per R&D Personnel
	1.8.5 Added Value of High-tech Industry per Personnel Engaged in S&T Activities 1.8.6 Transaction Value in Technical Market per Personnel Engaged in S&T Activities

Data source: China Science & Technology Statistics (http://www.sts.org.cn),
China Statistical Yearbook 1998-2010.

3.2 Data Preprocessing and Exploring

We choose water consumption per 10,000 Yuan GDP (m^3/ 10,000 Yuan, marked as water.GDP, with GDP at 2000 constant prices) as the dependent variable, and Regional Innovation Index of China (scaled scores between 0 and 100, marked as innov), water resource per capita (m^3, marked as water.s), proportion of the tertiary industry in GDP (%,marked as sector3) as independent variables. Water consumption per 10,000 Yuan GDP stands for the current level of water resource development. According to the commons ense, the greater the proportion of the tertiary industry in GDP is, the less water consumed by economic development will be. Obviously, the water consumption is influenced by local water resources, and water resource per capita is used for controlling variable.

Data of 31 mainland provinces of China is collected from 2000 (the beginning year of Regional Innovation Index of China) to 2009. To get a general idea of these variables, some descriptive statistics are firstly made on the pooled dataset.

The distributions of water consumption 10,000 Yuan GDP and water resources per capita are severely right-skewed, so the two variables are taken natural logarithm to be lwater.GDP and lwater.s. As showed below, the two distributions are much more symmetrical.

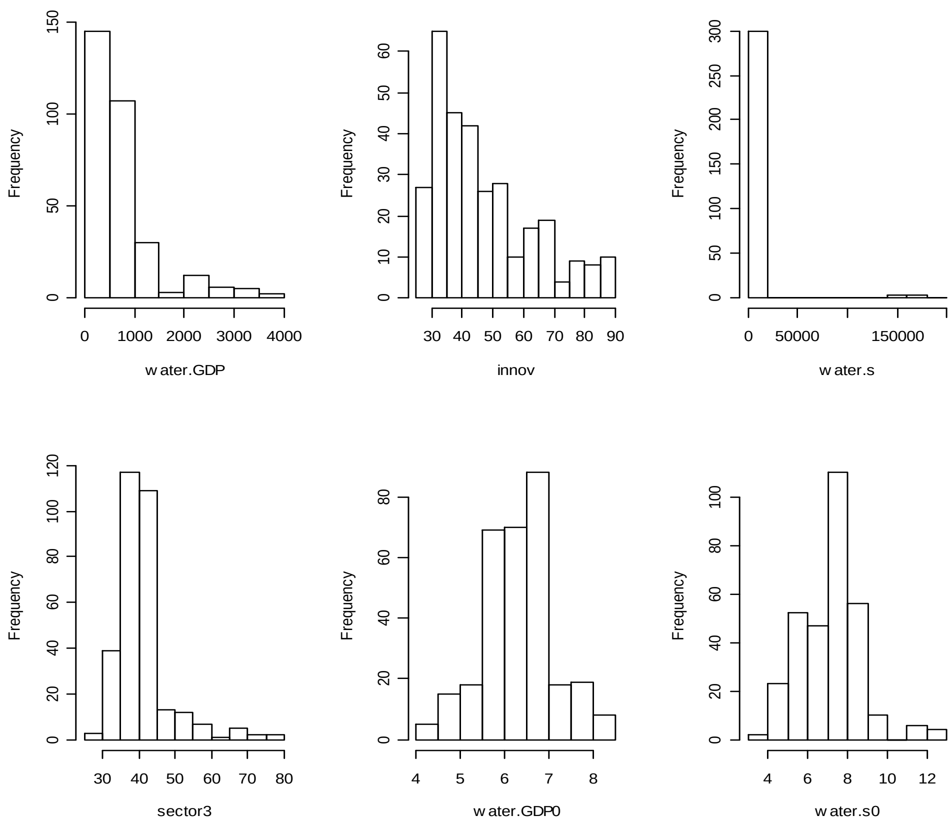


Figure 2: Distributions of 4 pooled variables and 2 log variables

Scatter plot of variables pairs of the four variables, there seems to be a significant negative correlation between water consumption per 10,000 Yuan GDP and Regional Innovation Index of China, and a positive correlation between water consumption per 10,000 Yuan GDP and water resources per capita. Both of them will be tested later with statistical techniques. As to the correlation between water consumption per 10,000 Yuan GDP and proportion of the tertiary industry in GDP, it remains obscure to tell.

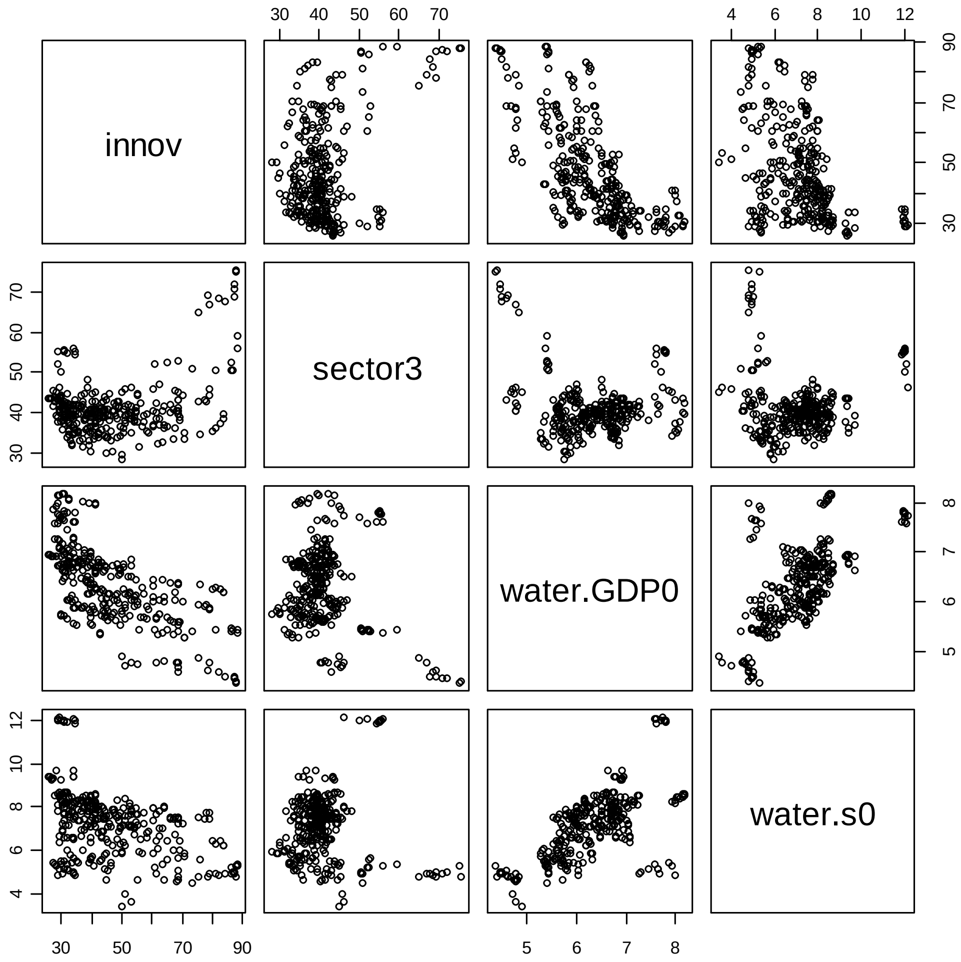
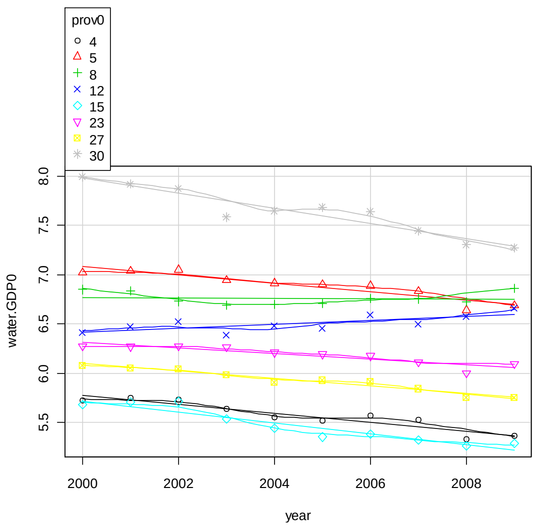
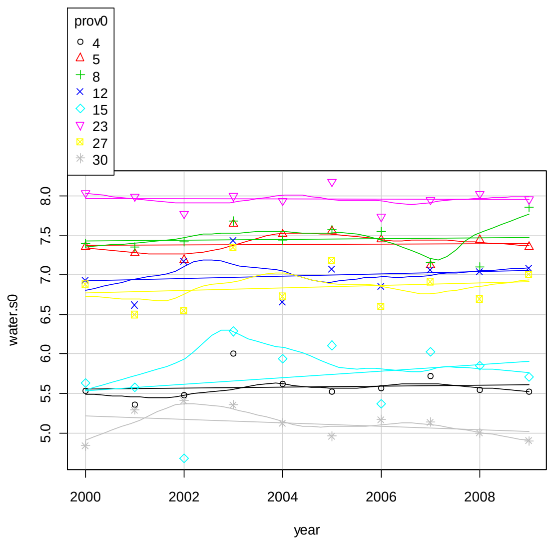


Figure 3: Scatter plot of variables pairs

More correctly, the trends of the four variables' panel data from 2000 to 2009 are demonstrated below. (Only ten provinces are randomly chosen for demonstration convenience.) Water consumption per 10,000 Yuan GDP of all the provinces decreases slowly, in accordance with the aims of the Government. Regional Innovation Index of China has a fast increasing trend. On the contrary, water resource per capita only varies slightly in different year, and proportion of the tertiary industry in GDP of some provinces goes down while some others go up. Now the negative correlation between water consumption per 10,000 Yuan GDP and Regional Innovation Index of China is confirmed again.





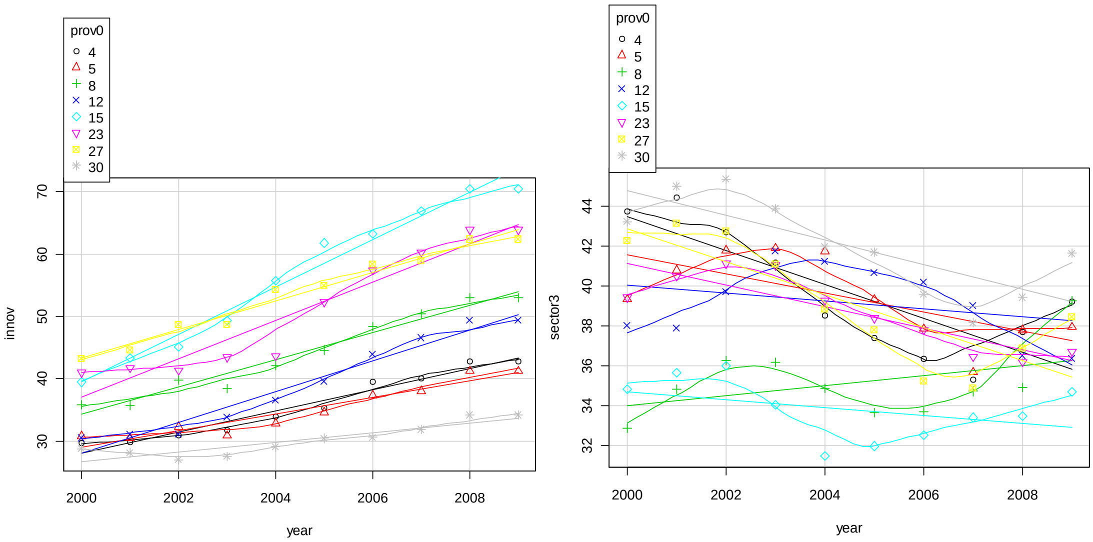


Figure 4: Changing patterns of variables in 10 sampled provinces

Heterogeneity across provinces and years are tested respectively. Even the dependent variable is taken natural logarithm, there still shows a high heterogeneity across the 31 mainland provinces, from below 5 to 8. On the other hand, heterogeneity across years shows a steadily shrink.

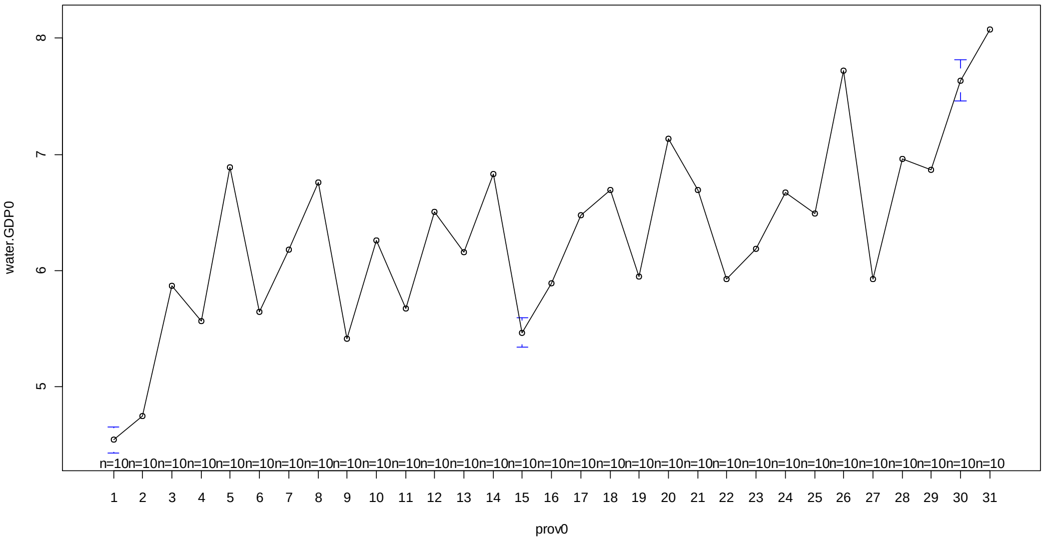


Figure 5-1: Heterogeneity across provinces

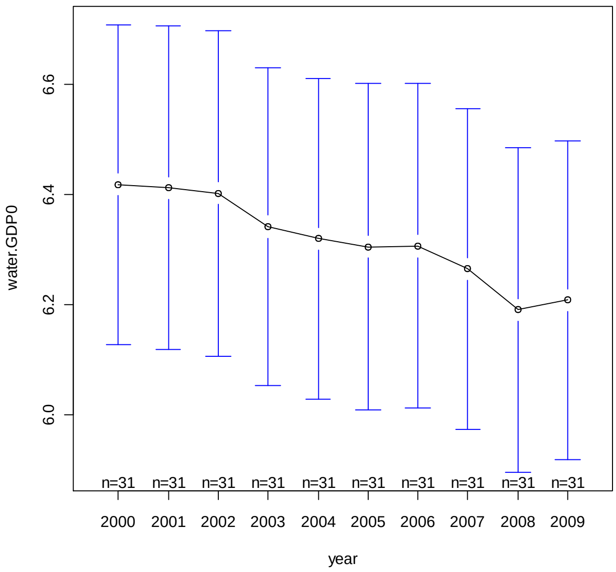


Figure 5-2: Heterogeneity across years

3.3 Fixed Effects Mean Regression

A possible panel data mean regression of fixed effects may naturally be

$$\text{lwater.GDP}_{it} = \ {}_{i} + \ {}_{1}\text{innov}_{it} + \ {}_{2}\text{lwater.s}_{it} + \ {}_{3}\text{sector3}_{it} + \ {}_{it}, \qquad (3)$$

and ${}_{i}$ is the fixed effects intercept, and ${}_{1}$ is the parameter we are interested most, it indicates how much lwater.GDP changes overtime, on average per province, when innov increases by one unit, controlling other independent variables.

Not surprisingly, the estimated coefficient of innov is negative -0.0088, indicating lwater.GDP decreases 0.0088 as innov increases one unit with other conditions remain the same. However, the estimated coefficient of lwater.s and sector3 may contradict the common sense and related economic theory. This contradiction is so confused that it drives us to seek for other more robust statistical techniques.

Table 2: Results of estimating fixed effects mean regression

	Estimate	**Std. Error**	**t-value**	**Pr(>|t|)**
innov	-0.0088	0.0008	-11.5419	< 2e-16
lwater.s	-0.0400	0.0206	-1.9403	0.0534
sector3	0.0050	0.0024	2.1012	0.0365

R-Squared: 0.3775; Adj. R-Squared: 0.3361

F-statistic: 55.7886 on 3 and 276 DF, p-value: < 2.22e-16

3.4 Fixed Effects Quantile Regression

The panel data quantile regression of fixed effects, which is established by Koenker (2004), can overcome some drawbacks of the normally assumed panel data mean regression. Koenker (2004) introduced penalized quantile regression to shrink the vector of individual effects, even though there remains to be some open research problems, it is still an attractive choice.

The estimated coefficients of lwater.s and sector3 change their directions, and the effect of innovation also becomes bigger. A reasonable model explanation can be addressed: lwater.GDP decreases about 0.01 as innov increases one unit with other conditions controlled, and this effect improves for lager conditional quantiles of lwater.GDP. The effects of lwater.s and sector3 are positive and negative respectively, and they diminish for lager lwater.GDP.

Table 3: Results of estimating fixed effects quantile regression

quantiles	**intercept**	**innov**	**lwater.s**	**sector3**
25%	5.9272	-0.0113	0.1188	-0.0022
50%	6.0517	-0.0119	0.1074	-0.0011
75%	6.2004	-0.0125	0.0985	-0.0013

4. Conclusions

DEA analysis reveals a distinct water use efficiency distribution among the 31 mainland provinces in China. The most developed regions and western regions severely scarce of water resource all reach the objective value of water use. The regions in the middle and south of China show lower efficiency. Provinces in the southeast of China are still lower. All of the regions in the north of China have the lowest efficiency. From the qualitative analysis, the efficiency distribution is to some extent correlated with the innovation.

According to the quantile regression of the panel data, the natural logarithm of water consumption per 10,000 Yuan GDP decreases about 0.01 as innovation index increases one unit with other conditions controlled, and this effect improves for lager water consumption. The effects of water resources and tertiary industry proportion are positive and negative respectively, and they diminish for lager water consumption.

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RÉSUMÉ (ABSTRACT)

With the rapid development, the ties between water resource and regional innovation capacity are getting increasingly close in China. What does the innovation capacity growth bring to the change of the water resource? Based on DEA analysis, this paper analyzes the efficiency of water use in different provinces, and comes to a preliminary conclusion that the efficiency distribution is to some extent correlated with the innovation. Focusing on the relationship between the two, this paper take a further step to introduce the regional innovation index of 31 mainland provinces in China designed by Renmin University of China, and then estimates the effect of regional innovation efficiency to water usage based on panel data, considering the heterogeneity across province and yea r, which helps to come up with targeted policy suggestions for the water supply and demand development in China building an innovative country.

Key Words: DEA; Regional Innovation Index; Quantile Regression; Panel Data