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Efficiency Analysis of China's Water Industry: From Perspective of Metafrontier and Cross-national Comparison

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Abstract

This paper introduces the leakage variable and estimates efficiency of 212 water plants in China, Russia, Poland, Bangladesh, Kazakhstan and Moldova from 2007 to 2012 by using the metafrontier model and directional distance function. The main conclusions are as follows: the technical efficiency of China's urban water industry is relatively low, and there is much room for improvement; but the efficiency gap between China and the world is narrowing.

Keywords: Efficiency; leakage; metafrontier; directional distance function (DDF); cross-national comparison

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I. Introduction

China is a developing country with more people and less water. Its per capita freshwater resources are only one fourth of the world's per capita. Water shortage is very common. At the same time, the leakage of network seriously affects the safety and efficiency of water supply. In 2015, the average leakage rate of urban public water supply in China reached 15.2%, which is far from that of developed countries. Therefore, reducing leakage rate and improving efficiency of urban water industry have become the key links of water resources management in China.

Chinese government initiated the market-oriented reform of municipal public utilities at the end of 2002 and encouraged private capital to invest in the water industry. From that on China's urban water industry has achieved "pulse" development. However, whether it is only due to the expansion of the scale or the improving overall efficiency needs further theoretical research and rigorous empirical testing. Some scholars believe that the efficiency after market-oriented reform has been improved (Saal et al.2007), while some find that the efficiency has declined (Molinos-Senante et al. 2015). To answer this question, we will use metafrontier method to make an cross-national comparative study on water supply efficiency of water plants in China, Bangladesh, Russia, Kazakhstan, Moldova and Poland from 2007 to 2012.

2. Model and data

2.1Model

Firstly, suppose that each water utility during the period t(t=1,2,...,T) uses N inputs $x_t = (x_{1t}, x_{2t},..., x_{Nt}) \in R_N^+$ to produce M "good" outputs $y_t = (y_{1t}, y_{2t},..., y_{Mt}) \in R_M^+$ and I "bad" outputs $b_t = (b_{1t}, b_{2t},..., b_{It}) \in R_N^+$ (Färe et al. 2007). We assume decision making units(DMUs) can be divided into G (G > 1) groups, which are divided by g (g = 1, 2,... G). The production possibilities set(PPS) consisting of input-output combinations contained in each group can be expressed as follows:

$$P_t^g(x) = \{(x_t^g, y_t^g, b_t^g): x_t^g \, can \, produce (y_t^g, b_t^g)\} \quad (1)$$

Under the condition of covering all samples, a metafrontier PPS enclosing all groups is constructed(Battase et al. 2004; O'Donnell et al. 2008).

$$P_t^M(x) = \{(x_t, y_t, b_t): x_t \, can \, produce (y_t, b_t)\} \quad (2)$$

Correspondingly, directional distance functions (DDF) with respect to group and metafrontier are respectively:

$$\vec{D}_t^g\left(x_t^g, y_t^g, b_t^g; \bar{g}\right) = \sup\left\{\beta : (x, y, b) + \beta\bar{g} \in P_t^g(x, y, b)\right\} \quad (3)$$

$$\vec{D}_t^M\left(x_t, y_t, b_t; \bar{g}\right) = \sup\left\{\beta : (x, y, b) + \beta\bar{g} \in P_t^M(x, y, b)\right\} \quad (4)$$

The direction vector $\vec{g} = \left(g_x, g_y, -g_b\right)$ indicates the direction of input and output change. β is the maximum feasible quantity of input, good output and bad output by increasing and reducing the same proportion to the production frontier.

The larger the DDF is, the farther the distance between the DMU and production frontier is. When DDF is zero, the DMU is on the production frontier. Our goal is to increase good output while reducing bad output and input, so the DDF based on VRS DEA method can be solved by the following linear programming equation:

$$\begin{aligned} &\vec{V}\left(x_t^{k'}, y_t^{k'}, b_t^{k'}; -x_t^{k'}, y_t^{k'}, -b_t^{k'}\right) = \max \beta \\ &s.t. \sum_{k=1}^{K} \lambda_t^k y_t^{km} \geq (1+\beta) y_t^{k'm}, m = 1,2,\cdots,M; \\ &\sum_{k=1}^{K} \lambda_t^k b_t^{kl} = (1-\beta) b_t^{k'l}, \quad l = 1,2,\cdots,L; \\ &\sum_{k=1}^{K} \lambda_t^k x_t^{kn} \leq (1-\beta) x_t^{k'n}, n = 1,2,\cdots,N; \\ &\sum_{k=1}^{K} \lambda_t^k = 1, \lambda_t^k \geq 0, k = 1,2,\cdots,K \end{aligned} \quad (5)$$

And the efficiency of water utility can be computed by this formula:

$$TE = \frac{1}{1+DDF} \quad (6)$$

Technology gap ratio (TGR) measures the distance between group frontier and metafrontier. $TGR = \frac{TE_M}{TE_G}$, TE_M is technical efficiency of metafrontier, TE_G is technical efficiency of group frontier. The higher the TGR of a water plant is, the closer the group production level (actual production level) is to the potential production level, that is, the higher the technical level is. Since the average TGR of all water plants in a country reflects the gap between the actual and potential technology levels , this indicator can also be used as the gap between a country and world's frontier that is comprised of sample countries.

2.2 Variables

Referring to previous studies (Molinos and Sala 2016), input variable chooses the operation cost, staff, total assets while output variable chooses the water produced and leakage water. Among them, operation cost is the annual operation cost of water supply service after deducting personnel cost divided by annual water sales. Staff is workers per 1000 people served. Staff and water produced is daily amount of water supply per capita. Total assets are expressed by the water plant assets per water sales. And we takes 2010 as the base period and deflates operating costs and total assets denominated in U.S. dollars by adjusted GDP deflator index.

2.3 Data

We calculate 212 water plants in Bangladesh, China, Kazakhstan, Moldova, Poland and Russia from 2007 to 2012. All data comes from IBNET (International Benchmark Network).

3. Empirical analysis

3.1Kruskal-Wallis test

Kruskal-Wallis nonparametric test is used to verify the heterogeneity of production frontier（Tsagarakis 2013）.The hypotheses are as follows:

H_0 =six country samples operate under the same production frontier;

H_1 =some of six country samples operate under other production frontiers:

When the p value exceeds 0.05, the original hypothesis is accepted, and there is no heterogeneity in the production frontier. Otherwise, reject the original hypothesis and the production frontier is heterogeneous.

Test results are shown in Table 1. The p value of five variables is less than 0.05, so the difference of variables in six countries is statistically significant. It shows that efficiency analysis based on a single production frontier assumption can not analyze the efficiency of water plants from different countries.

Table 1. Kruskal-Wallis test statistics.

	operation cost	total assets	staff	leakage	water produced
Chi-squared	707.38	307.96	686.78	409.23	812.82
p value	<0.001	<0.001	<0.001	<0.001	<0.001

3.2 The model and empirical results

We calculates group frontier efficiency and metafrontier efficiency of the six countries from 2007 to 2012, and calculates the average and standard deviation, as shown in Table 2.

Firstly, for the efficiency of group frontier, the average of each country varies greatly over the years, from 0.687 in Russia to 0.948 in Poland. The annual average standard deviation of group frontier efficiency shows that Poland's standard deviation is the smallest, which is 0.096, indicating that Poland's waterworks are of high homogeneity. The group frontier efficiency in Russia and Moldova are 0.235 and 0.241, indicating that the heterogeneity in the two countries is high. On average, group frontier efficiency is higher than metafrontier efficiency. For example, the average of group frontier efficiency in China is 0.863, which means that there is room for improvement of the operation cost to reduce by 14%.

Next, we compare the number of effective manufacturers at the production frontier in each country. The left column of Table 2 shows that effective manufacturers in Poland, Bangladesh, Kazakhstan and China are all over 50%. Only 35.29% of Moldova's and 19.68% of Russia's water plants are on the effective frontier, which is similar to the conclusions of Molinos and Sala (2016). This paper estimates that the proportion of effective manufacturers in China is 52.3%, which means that 47.7% of China's water plants have room for improvement in input or output.

Table 2. DEA estimates of technical efficiency with respect to group frontiers and to the metafrontier.

	Efficiency score with respect to group frontiers			Efficiency score with respect to the metafrontier		
	mean	s.d	% efficient	mean	s.d	% efficient
Bangladesh（n=78）	0.911	0.141	64.10%	0.785	0.231	46.15%
China（n=174）	0.863	0.180	52.30%	0.523	0.226	7.47%
Kazakhstan（n=108）	0.853	0.195	54.63%	0.664	0.267	28.70%
Moldova（n=204）	0.729	0.241	35.29%	0.127	0.054	0.00%
Poland(n=78)	0.948	0.096	71.79%	0.638	0.244	23.21%
Russia（n=630）	0.687	0.235	19.68%	0.601	0.240	12.06%

The second step is to make a comparative analysis of the efficiency of countries with respect to metafrontier. As the theory reveals, metafrontier efficiency is lower than group efficiency, as shown in Figure 1. However, the reduction of technical efficiency for different frontier is also very different between countries. Moldova, China and Poland have the greatest reduction in the efficiency, with Moldova falling by 0.5, China by 0.34 and Poland by 0.31. This again demonstrates the importance of using the metafrontier to measure the cross-national technical efficiency differences.

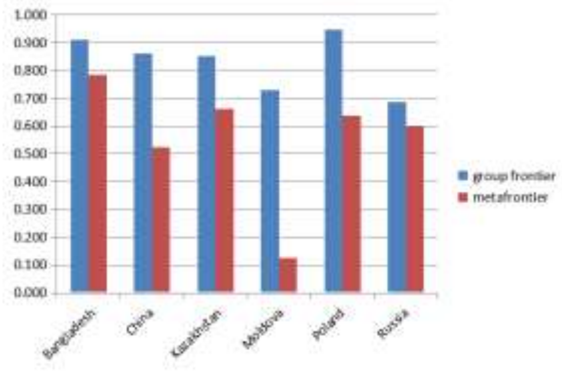

Figure 1. Technical efficiency comparison of metafrontier and group frontier.

Under the metafrontier, the number of effective manufacturers in various countries has also decreased significantly, with Moldova and China having the largest reduction in the proportion. The proportion of effective firms in Moldova has decreased from 35.29% to 0, while that in China is only 7.47%, which is much lower than 52.3% of the group frontier calculation. This shows that the method of technical efficiency based on group frontier is not suitable for cross-national comparative analysis , while the metafrontier method can better deal with the problem of efficiency comparison between countries with different production technologies (Wang et al. 2013).

4. TGR analysis: Does the gap between China and the world in water industry widen?

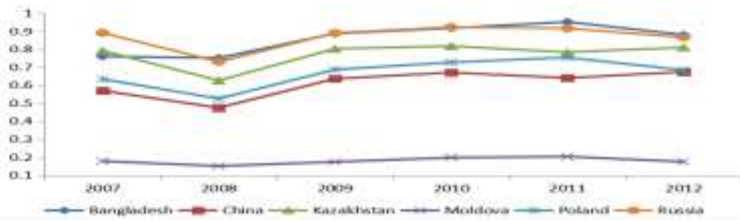

Figure 2. Trends in TGR of water industry in countries from (2007-2012).

Figure 2 shows that the TGR of China's urban water industry is on the rise in general, indicating that the gap in water industry between China and the world is narrowing. So there is obvious technological progress in China' water industry. However, the process of technological progress is not smooth. The TGR of China is in the stage of technological retrogression between 2007-2008, in the stage of rising between 2008-2010.While the TGR slightly declined between 2010-2011 for the world financial crisis, and constantly approaching the technological frontier of the six countries between 2011-2012.

5. Conclusion

Under the background of the increasing shortage of water resources in the world, more and more industrial policy makers, water plant managers and researchers are paying attention to the efficiency of urban water services. Improving the operational efficiency of urban water services has become the only way to achieve high-quality development of urban water industry. From the perspective of cross-national comparison, this paper considers the heterogeneity of enterprises and incorporates leakage water variables into output variables. The water supply efficiency of 212 water plants in China, Russia, Poland, Bangladesh, Kazakhstan and Moldova from 2007 to 2012 is estimated by using metafrontier approach and DEA model. First of all, from a cross-national perspective, although the gap between China and the world in water industry has narrowed in recent years, the overall technical efficiency is still low, and there is still room for further improvement. Secondly, leakage is an important factor affecting the efficiency measurement of water industry, and the efficiency measurement of water industry which neglected leakage water factor in the past is inaccurate.

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References

[1] Battese, George E., D.S. Prasada Rao and Christopher J. O’Donnell,A Metafrontier Production Function for Estimation of Technical Efficiencies and Technology Gaps for Firms Operating under Different Technologies, *Journal of Productivity Analysis,* **1** (2004), 91-103. https://doi.org/10.2307/41770148

[2] Chung,Y., Färe R.and Grosskopf S,Productivity and Undesirable Outputs: A Directional Distance Function Approach, *Journal of Environmental Management*, **3** (1997), 229 240. https://doi.org/10.1006/jema.1997.0146

[3] Färe R, Grosskopf S, Jr. C. A. P., Environmental production functions and environmental directional distance functions, *Energy*, **7** (2007), 1055-1066. https://doi.org/10.1016/j.energy.2006.09.005

[4] Molinos-Senante,M., Sala-Garrido,Cross-national comparison of efficiency for water utilities: a metafrontier approach, *Clean Technologies & Environmental Policy*, **5** (2016), 1-9. https://doi.org/10.1007/s10098-016-1133-z

[5] Molinos-Senante, M., Maziotis, A., Sala-Garrido, R.,Assessing the relative efficiency of water companies in the English and welsh water industry: a metafrontier approach, *Environmental Science & Pollution Research*, **22** (2015), 16987-16996. https://doi.org/10.1007/s11356-015-4804-0

[6] O'Donnell,Christopher J.,D.S.Prasada Rao and George E.Battese, Metafrontier Frameworks for the Study of Firm-Level Efficiency and Technology Ratios, *Empirical Economics*, **2** (2008), 231-255. https://doi.org/10.1007/s00181-007-0119-4

[7] Saal D. S., D. Parker, T. W. Jones,Determining the Contribution of Technical Change, Efficiency Change and Scale Change to Productivity Growth in the Privatized English and Welsh Water and Sewerage Industry: 1985 - 2000, *Journal of Productivity Analysis*, **28** (2007), 127-139. https://doi.org/10.1007/s11123-007-0040-z

[8] Tsagarakis K.P., Does size matter? Operating cost coverage for water utilities, *Water Resour Manag.*, **5** (2013), 1551-1562. https://doi.org/10.1007/s11269-012-0256-1

[9] Wang Q, Zhang H, Zhang W,A Malmquist CO2 emission performance index based on a metafrontier approach, *Math. Comput. Model.*, **5** (2013), 1068–1073, https://doi.org/10.1016/j.mcm.2012.05.003

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