Comparisons of efficiencies between two types of DMUs: An application to Japanese public water companies

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[Abstract] It is natural to assume that due to different sources of water such as surface water and groundwater, water utilities would have different production technologies. Although there are many empirical studies measuring efficiency, productivity and/or returns to scale for water supply organizations, almost all of them neglect variety in the sources of water available to each. The main purpose of this study is to compare the efficiencies of two types of decision-making units (DMUs) i.e. water companies whose major source is underground as against those whose major source is non-underground. In this study, using observations of Japanese public water companies, we will apply the rank-sum-test of the data envelopment analysis (DEA) approach developed by Wilcoxon-Mann-Whitney to see whether differences between the two groups are significant.

[JEL Classification] **L95, L11**

[Key Words] rank-sum-test, efficiency, water companies

1. Introduction

Due to environmental and geographical constraints, water companies have adapted to various situations. For example, a water supply system that is composed of water production facilities and transmission facilities obtains water from various sources, such as surface water and groundwater. Water companies without their own sources purchase water from other water utilities or wholesale agencies.

There is no doubt that water-purifying levels differ among water suppliers, due to differing sources. Water suppliers also need water supply plants specific to the requirements of their sources.

Over the past few decades, a considerable number of studies have tried to measure efficiencies, productivities and/or scale economies for water supply organizations, but unfortunately almost all of them have failed to account for differences due to technical differences between water sources.

The main purpose of our study is to show statistically that observations from different supply conditions are sampled from different populations. To investigate this, we apply a rank-sum-test (the Wilcoxon-Mann-Whitney test) to the efficiencies obtained from data envelopment analysis (DEA).

We use observations of Japanese water utilities because their supply conditions are so diversified that they need to identify whether some groups are sampled from the same population or not. If we find that they come from different populations, we will be able to estimate appropriate measures of efficiency, productivity and/or scale economies for each group.

Section 2 of this article contains an overview of the Japanese water industry. Sections 3 and 4 present the method and the data to be analyzed. Section 5 presents our results. Concluding remarks are summarized in Section 6.

2. An overview of the water industry

Water supply systems in Japan are mainly operated by local authorities of cities, towns and villages. They are divided into three groups: large water supply, small water supply and small private water supply. A large water supply is a system where the population served is more than 5,001, and a small water supply serves between 101 and 5,000 people. A small private water supply is the water supply system in buildings that is equipped with receiving water tank(s) with a capacity of more than 10m^3 and that receives potable water from a large or a small water supply. The number of these water utilities and population served are shown in Table 1. We can see from this table that although there are many small water utilities, almost all consumers (about 90.7%) are supplied by a large water supply. The existence of a large number of small water companies has been caused mainly by the special geographical conditions of Japan. It is difficult to get sufficient data from small companies, so we are going to discuss only large water supply systems.

Table 1 Population Served and Total Population (FY2000) (in thousands)

Total Population	Population Served				Percentage of Population Served
	Large water supply n=1,962	Small water supply n=9,195	Small private water supply n=3,784	Total n=14,941	
126,755	115,001	6,552	631	122,184	96.4

(Source): Annual Statistics of Local Public Corporations

Due to geographical and historical restrictions, it has become difficult for Japanese water utilities to obtain water. Table 2 shows the variation between sources of water supply and different types of ownership. In Japan, almost all water supply systems are owned by municipal governments of prefectures, cities, towns and villages, and some are jointly owned by a number of municipal governments. Water companies in Japan obtain their water mainly from surface water (dam and non-dam) and wells. Those without their own water sources must buy their water from other water companies or wholesale agencies. We can see from Table 2 that up to 60% of water utilities obtain their water from mixed sources.

Table 2 Number of water supply systems for different water sources in FY2000

		Water sources					
		Purchased water	Surface water (non-dam)	Surface water (dam)	Well	Mix	Total
Ownership	Prefecture	0	0	0	0	4	4
	City	41	22	5	103	423	594
	Town and Village	102	78	10	409	623	1,221
	Joint	9	9	2	11	47	78
	Total	152	109	17	523	1,097	1,898

(Source): Annual Statistics of Local Public Corporations

(Note):

(1) Mix means water companies that obtain water from a combination of surface water (non-dam), surface water (dam) and wells.

(2) Joint means the water company is jointly owned by a number of municipal governments.

We consider their water supply systems with different water sources have different production technologies. Table 3 shows the partial factor productivity (PFP) of labor, capital and material for water utilities with different water sources.

We can see from this table that the average productivity of water utilities that obtain water from wells is higher than others. The reason for this is that water from a well is of such high quality that well-supplied water supply systems do not need much purification. On the other hand, the productivity of water utilities that obtain water from dams is lower than others. There are two reasons for this. One is that dams are expensive and the other is that the quality of water from a dam requires a high level of purification.

Table 3 PFPs for water supply systems with different water sources in FY2000

	Purchased water	Surface water (non-dam)	Surface water (dam)	Well
PFP_L	366.14	256.31	265.95	382.40
PFP_K	1.03	0.85	0.82	1.05
PFP_M	17.20	26.95	20.75	32.43

(Source): Annual Statistics of Local Public Corporations

(Note): PFPs are calculated as follows;

PFP_L : annual total water delivery (million m^3) / employees

PFP_K : annual total water delivery (million m^3) / fixed assets (1000 yen)

PFP_M : annual total water delivery (million m^3) /index of input materials*

*Index of water materials is defined as the total cost excluding labor and capital cost (1000 yen)

From the above discussion, it is natural to assume that different water sources would require different production technologies. In other words, observations of water utilities with different water sources are sampled from different populations. We present our methodology in the next section.

3. Methodology

3.1 Data Envelopment Analysis

We use data envelopment analysis (DEA) to measure efficiency. DEA involves the use of linear programming methods to construct a non-parametric piece-wise surface over the data. DEA is referred to as a non-parametric method because efficiency measures are calculated relative to this surface.

The representative DEA model is CRS (constant returns to scale) (Charnes et al. (1978)). We use the input-oriented CRS model because many previous estimates of cost functions in Japan have shown constant returns to scale (e.g., Mizutani and Urakami 2001).

We assume that there are data on K inputs and M outputs for each of N public water companies. For the i-th company these are represented by the column input vectors $\mathbf{x}_i$ and output vector $\mathbf{y}_i$. The input-oriented CRS model is as follows:

$$\begin{aligned} &\min \ \theta \\ &\text{s.t.} \quad -\mathbf{y}_i + \mathbf{Y}\boldsymbol{\lambda} \geq \mathbf{0} \\ &\qquad \theta\mathbf{x}_i - \mathbf{X}\boldsymbol{\lambda} \geq \mathbf{0} \\ &\qquad \boldsymbol{\lambda} \geq \mathbf{0} \end{aligned}$$

where $\mathbf{X}$ is the input matrix ($K \times N$), $\mathbf{Y}$ is the output matrix ($M \times N$), and $\boldsymbol{\lambda}$ is the nonnegative vector. θ is a scalar and represents technical efficiency of the i-th company. The range of θ is between zero and unity. The value of θ is normalized at unity for the most efficient water company.

3.2 Rank-Sum-Test

Since the theoretical distribution of the efficiency score in DEA is usually unknown, we use the non-parametric Wilcoxon-Mann-Whitney test. This can tell us whether two independent groups have been drawn from the same distribution. By doing this, we can see whether two groups have the same production technology or not.

If we have samples from two populations (A and B), m is the number of DMUs belonging to group A, and n is the number of DMUs belonging to group B. The null hypothesis is:

H0: The efficiencies of two groups have the same distribution.

We obtain the statistical index S by summing the ranking of group A. S follows an approximately normal distribution with mean $m(m+n+1)/2$ and variance $mn(m+n+1)/12$. By normalizing S, we have:

$$T = \frac{S - m(m+n+1)/2}{\sqrt{mn(m+n+1)/12}}$$

T has an approximately standard normal distribution. Cooper et al. (2000) explain applications the Wilcoxon-Mann-Whitney test to DEA.

4. Data

In order to create relatively similar demand conditions, we select observations from the same region. The selected observations are 119 companies from the Tokai area and all companies are owned by municipal (city, town, or village) governments. The data comes from the *Annual Statistics of Local Public Corporations FY2000* (Chiho Koei Kigyo Nenkan FY2000) issued by the Ministry of Local Government. We divided these water companies into three groups based on their differing water sources.

Group 1: 100% purchased water (35 companies).

Group 2: 100% well (55 companies).

Group 3: Companies that use any surface water (29 companies)

In our analysis, we assume that water companies produce one output (water) using three inputs (labor, capital, and materials). We define each variable as follows:

Input (1): Number of persons employed

Input (2): Tangible fixed assets (million yen)

Input (3): Index of water materials, which is defined as total cost excluding labor and capital cost (million yen)

Output (1): Annual total water delivery (1000 m^3)

We show the summary statistics for these variables in Table 4, 5 and 6.

Table 4 Summary Statistics for Group 1

	Mean	Standard Deviation	Maximum	Minimum
Output (1)	4,943	4,025	14,687	705
Input (1)	10	7	25	2
Input (2)	5,225	4,621	16,969	457
Input (3)	256	209	870	49

Table 5 Summary Statistics for Group 2

	Mean	Standard Deviation	Maximum	Minimum
Output (1)	7,017	12,602	59,262	519
Input (1)	13	22	116	1
Input (2)	5,313	8,409	47,108	345
Input (3)	198	365	2,229	15

Table 6 Summary Statistics for Group 3

	Mean	Standard Deviation	Maximum	Minimum
Output (1)	4,787	7,338	35,316	572
Input (1)	12	14	62	1
Input (2)	4,980	6,447	29,771	558
Input (3)	146	229	1178	18

5. Results

First, we apply DEA to the pooled data for Groups 1 and 2 and measure the efficiencies, using Zhu's DEA Excel Solver Software (Zhu (2002)). We show the results in Table 7. We see that the average efficiency of Group 1 is 66.8%, while that of Group 2 is 44.1%. We test the null hypothesis that Group 1 and Group 2 are drawn from the same population using the Wilcoxon-Mann-Whitney test. This test statistic (obtained from Stata 7.0) is also shown in Table 7. The result implies a rejection of the null-hypothesis. We conclude, therefore, that the distribution of efficiency of Group 1 differs from that of Group 2.

Table 7 Summary results of efficiency for Group 1 and Group 2

	Pooled data	Group 1	Group 2
Mean	0.592	0.688	0.441
Standard Deviation	0.198	0.176	0.121
Maximum	1.000	1.000	0.681
Minimum	0.223	0.336	0.223
Wilcoxon-Mann-Whitney Test		6.104***	

(Note): *** shows p < 0.01

Second, we apply DEA to the pooled data for Groups 1 and 3 and measure efficiencies. We show these results in Table 8. We see that the average efficiency of Group 1 is 65.2%, while that of Group 3 is 71.6%. We test the null hypothesis that

Group 1 and Group 3 are drawn from the same population using the Wilcoxon-Mann-Whitney test, and the result is shown in Table 8. Contrary to the above result, this result implies an acceptance of the null-hypothesis. We conclude that the distribution of efficiency of Group 2 is the same as that of Group 3.

Table 8 Summary results of efficiency for Group 1 and Group 3

	Pooled data	Group 1	Group 3
Mean	0.687	0.652	0.716
Standard Deviation	0.194	0.195	0.191
Maximum	1.000	1.000	1.000
Minimum	0.214	0.214	0.384
Wilcoxon-Mann-Whitney Test		-1.356	

6. Concluding Remarks

In this paper, we have tested whether the efficiency of three groups of Japanese water companies which have different water sources have the same distribution or not. We have applied the Wilcoxon-Mann-Whitney test to two pairings of these groups using the efficiencies obtained from a DEA analysis to ascertain whether the pairs are drawn from the same population. After pooling data for Group 1 (the water source is 100% purchased water and the average efficiency is 66.8%) and Group 2 (the water source is 100% well and the average efficiency is 44.1%), the null hypothesis that the efficiencies of Group 1 and Group 2 have the same distribution is rejected. We carry out the same test between Groups 1 (average efficiency 65.2%) and 3 (the water source is any surface water and the average efficiency is 71.6%). The null hypothesis is that Groups 1 and 3 are sampled from the same population is accepted.

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