Incorporating water purification in efficiency evaluation:
Evidence from Japanese water utilities

Theara Horn

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Abstract
Water production and service quality have been used as dimensions of efficiency evaluation in previous studies of water utilities’ performance. This study attempts to show that the inclusion of water purification efforts should be another crucial dimension in the efficiency measurement. We use a stochastic cost frontier to estimate the technical efficiency of 392 Japanese water utilities in 2005. The results show that a water purification effort may increase cost, and that its inclusion in efficiency evaluation leads to some specific changes in efficiency score and the ranking of water utilities. Furthermore, this incorporation enables the impact of different qualities of source water on efficiency to be controlled. The result suggests that in order to encourage water purification efforts, it is crucial to incorporate purification in benchmarking.

Keywords: Water utilities, Water purification, Stochastic Cost Frontier
JEL: D24, H49, L51

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† Graduate School of Economics, Osaka University, 1-7Machikaneyama, Toyonaka, Osaka, 560-0043, Japan; E-mail: hge016ht@mail2.econ.osaka-u.ac.jp
1. Introduction

The coverage of the water service in Japan is admirably high, at up to 97.3% in 2006. However challenges remain in improving performance further. Japanese water utilities are independently run by local municipal authorities. There is no competition between these utilities, and the result is a form of natural monopoly. So it is likely that there are few incentives to improve performance. Moreover, water tariffs are set using a cost-covering system (Sokatsugenkahoshiki in Japanese), in which the expenditure of the water utilities is covered by the revenue collected from the water charge. Under this price-setting system, differences among utilities in such characteristics as location and performance result in large differences in water tariffs. In 2005 the highest price of drinking water per 10 m$^3$ was more than 10 times the lowest price. As drinking water is seen as an inelastic good for water users, this price gap should be reduced to create more price equality.

Following the amendment of the Water Act in 2001, private participation and the introduction of the PFI method are now allowed in such sectors as the management of water facilities and water quality examination, in order to improve performance and reduce costs. Since Japan faces a declining population in the near future, cost reduction and performance efficiency are considered essential in reducing the burden on those who pay water charges (Water Vision 2008, p.19). The introduction of regulations such as a price cap or yardstick is considered likely to promote competition among utilities and to ensure lowest-cost production (7th Review session on water vision 2004). In the future, if such a regulation can be adopted, water utilities will have to operate subject to comparison with each other. In this context, to realise how efficiently utilities operate their service, the measurement of efficiency is crucial, and the indicators used in efficiency evaluation must be examined thoroughly, to ensure that regulation will not adversely affect the quality of water$^1$.

In recent years, previous studies have argued the case for several different methods and indicators. Nakayama (2002) estimates the efficiency of 594 water utilities using both the method of the stochastic production frontier and data envelopment analysis (DEA), with the annual volume of water delivered as the output. Mizutani and Uragami (2001) estimate the network density and scale economy of Japanese water utilities in 1994, by integrating two variables of output quality into the cost function. The first output quality is the purifier level, which is the ratio of annual clear water volume to the annual designated volume of water-intake. The second output quality is the ratio of residential water delivery to total water consumption. However, their study does not focus on efficiency measurement, and the water quality used for the estimation does not relate directly to the chemical purification level of raw water. In Japanese case studies of efficiency measurement, the quantity of water delivered is usually the main indicator of output, whereas the quality of drinking water supplied has, as

$^1$ Sappington (1994) presents a detailed discussion of how regulatory policy design should be undertaken, if it is to ensure the quality of goods whose producer firms are regulated.
far as I am aware, not yet been taken into account, possibly because of problems regarding data availability.

Considering water quality, Saal et al. (2007) estimate the quality-adjusted input distance function, in order to estimate the productivity growth rates in privatised English and Welsh water supply for the period 1985–2000. The Water Quality Index is determined by the average percentage of chemicals compliant with the standard level of key quality parameters, as chosen by Ofwat. (The same measurement method is also employed in Saal and Parker (2000, 2001)). Similarly, Woodbury and Dollery (2004) use the DEA model to estimate the performance efficiency of Australian water services by incorporating water quality in the evaluation. The study used data on 73 water supply authorities to estimate various models, and examined water and service quality indices. The water quality index is defined similarly to that of Saal and Parker (2007), as the percentage of chemical compliance with the drinking water quality required to meet the standard value. The service quality index includes water quality complaints, service complaints, and average customer outage.

In a case study in Peru, Lin (2005) uses a stochastic cost frontier to estimate the efficiency of Peruvian water utilities from 1996 to 2001, by incorporating service quality into the estimation model. The service quality indices consist of the accounted-for water ratio, the positive rate of the chlorine test, service coverage and service continuity. The study shows the importance of service quality, which should therefore be included as another dimension by which to compare the performance of the water and sewerage service industry.

In previous studies, the service quality and quality of distributed water are usually considered as indicators, presumably because they relate to the customers’ health. However, regarding water quality, purification may relate to the performance of the water utilities, because raw water is purified in advance before the water is distributed. Though the quality of the water distributed is exactly the same, the amount purified may differ among utilities, depending on the quality of the raw water withdrawn from their water source, and the purification effort require1. Moreover, different kinds of water sources, such as surface water or dam, may influence the cost structure (Urakami, 2006).

This study attempts to show empirically that the amount of chemicals purified from raw water is another important variable that should be included in the efficiency evaluation, by estimating 392 Japanese water utilities data in 2005 with the stochastic cost frontier. First, we aim to prove that the purified amount may affect the efficiency score and ranking. If purification is not considered, water utilities that make an effort to purify water may be assessed erroneously. Second, we do the Tobit regression to determine, which factors affect performance efficiency. The result shows that, by incorporating purification into the efficiency evaluation, the influence of different water sources can be controlled.

This paper is organised as follows. First, section 1 provides a description of the water

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1 See Appendix for the distribution of the purified amount of raw water quality.
purification process. Next, section 2 presents the estimation methodology, and section 3 considers the data. Section 4 reports the empirical estimation result and, finally, section 5 presents the conclusion.

2. Water Purification
To distribute drinking water to households, water utilities engage in three main steps: raw water intake, water purification, and water distribution. To ensure that good and safe water is distributed to customers, the standard level of chemical substances in delivered water is set by a rule, and water utilities distribute water that complies with it. In Japan and many other countries, the standard level conforms to the guidelines for drinking water quality determined by the World Health Organisation (WHO). From our conversation with a staff member of the Murano water purification plant, we learned that the quality of delivered water must basically follow this rule. However, it may be that some water utilities do their own research, and set their own quality target, which complies with the WHO guidelines, and provides drinking water that has an even better taste. The quality of supply water may differ among utilities.

Raw water contains several substances, some of which may be harmful to health if the appropriate purification is not conducted. For example, standard plate count bacteria, Escherichia coli, are among the substances that are sources of disease, and they can be disinfected by chlorination (i.e. the disinfection-only method). Chlorination is not difficult, and it can be undertaken cheaply, simply by introducing chlorine into water. However, if the raw water contains other matter, such as organic substances\(^5\), the process of purification required to reduce or remove those substances from the water before chlorination is done, is more sophisticated because the vulnerable reaction of chlorine with organic matter can produce another substance called Trihalomethane (THM), which is considered a cause of diseases such as cancer\(^6\). Besides chlorination, several other methods can be used in the purification process, including coagulation, sedimentation and filtration. Recently, to upgrade the capacity of purification, a more advanced method, in which ozonation\(^7\) is used in purification, is available to certain utilities. Such a sophisticated method may lead to higher costs, as it requires more capital, labour, energy, maintenance and so forth.

Accordingly, the purified amount of raw water may be an important element that should be incorporated into the efficiency evaluation, to provide a fairer judgment of the performance of utilities, because it may affect the operating cost of water, given the different qualities of raw water drawn from a variety of kinds of water source, and the different qualities of water delivered.

\(^5\) Organic substance refers to polluted matter in raw water coming from the inflow of waste from households and industry into the water source.

\(^6\) Detailed information on this issue is available in Moniwa (2007, p.55) and Steel and McGhee (1979, p.274).

\(^7\) Ozonation is used in a sophisticated purification method in which ozone is infused to help destroy bacteria and other microorganisms. Ozonation is seen as more effective in disinfection than chlorination. It is capable of reducing the formation of THM.
3. Methodological Consideration and Model Specification

3.1. Stochastic cost frontier

This study uses the stochastic cost frontier (SFA) in log-linear form to estimate the efficiency of Japanese water utilities. The reasons for choosing the cost function are the advantage of the noise term in the model, which gives the estimated result statistical reliability, the possibility of multiple outputs, and the assumption of cost minimisation to a given level of output, which is parallel to the policy aiming at cost reduction\(^8\).

The cost function is defined as

\[ C_i = C(y_i, w_i, \beta) \exp(u_i + v_i) \tag{1} \]

\(y_i\): Scalar outputs, \(w_i\): vector of input prices, \(\beta\): Parameters,
\(C(y_i, w_i, \beta)\exp v_i\) is the stochastic cost frontier for the given output and input prices.
\(v_i\) represents statistical noise, which is assumed to be normally distributed by \(N(o, \sigma^2)\).
\(u_i\) indicates a cost inefficiency term, which is the distance from the observed cost to the minimum costs on the frontier and own non-negative value (\(u_i \geq 0\)).

Two of the commonly used half-normal and exponential distributions are suggested for \(u_i\)\(^9\):

- \(u_i \sim iid\) exponential (Exponential model)
- \(u_i \sim iid\) \(N^+ (o, \sigma^2)\) (Half-normal model)

Taking the natural logarithm of both sides of the equation (1), we get

\[ \text{Ln} C_i = \text{Ln} C(y_i, w_i, \beta) + u_i + v_i \tag{2} \]

The cost inefficiency score is determined through the prediction of individual water utility from the stochastic cost frontiers. It is calculated by the ratio of observed cost to frontier cost.

\[ \text{Cost inefficiency} = \frac{E(C_i|u_i, w_i, y_i)}{E(C_i|u_i = 0, w_i, y_i)} \tag{3} \]

where \(C_i\) is the cost function in equation (1). \(E(.)\) represents the expected value. The cost inefficiency value is between 1 and infinity.

3.2. Model specification

To show the importance of the amount of water purified as an indicator in the efficiency measurement, two alternative models are estimated. First, only the delivered water volume is used as output; and, second, the amount of water purified and the water volume are jointly used as outputs in the Stochastic Cost Frontier (SCF). In this paper, the purified amount of Total Organic Carbon (TOC) is used as a proxy variable of the water purification outcome because of data availability, and the importance of this substance in relation to the cleanness

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\(^8\) Detailed information on SFA is available in Kumbhakar and Lovell (2003).

\(^9\) Truncated-normal distribution for \(u_i\) is also estimated, but it encountered convergence problems.
of water\textsuperscript{10}.

**Models of SCF model estimation**

- **Model A**: TOC is not included in the cost function

\[
\ln(\text{Operating cost}_i) = c + \beta_1 \ln(\text{waterproduction}) + \beta_2 \ln(\text{capitalprice}) + \\
+ \beta_3 \ln(\text{laborprice}) + u_i + v_i 
\]  

\text{(4)}

- **Model B**: TOC is included in the cost function.

\[
\ln(\text{Operating cost}_i) = c + \beta_1 \ln(\text{waterproduction}) + \beta^* \ln(\text{TOC}) + \beta_3 \ln(\text{capitalprice}) + \\
+ \beta_3 \ln(\text{laborprice}) + u_i + v_i 
\]  

\text{(5)}

In the model, the restriction of homogeneity of degree one of the cost function is not set in factor prices because, besides labour and capital prices, the price of other materials is hard to define due to data availability\textsuperscript{11}.

The slope parameters of water production, capital price, and labour price are expected to be positive, based on economic theory. Furthermore, the slope parameter of the purified amount of TOC will be positive, because the cost of purification may increase the operating cost.

4. **Data Consideration**

The study uses 392 Japanese water utilities as sample data (the total number of water utilities in 2005 was 1449). Some samples are excluded for the following reasons. Data with a value of zero are omitted because the variable is used in logarithmic form. To calculate the purified amount of TOC, data on both raw water and the supplied water quality must be available. In the case in which both these types of data of utility are not available (i.e. missing value), the computation of the purified amount is impossible, and these data are therefore removed from the sample. In addition, some water utilities that operate in the form of a water association are also excluded from the sample, given concern about the bias that may result from the effect of scale economy.

Operating cost is the summation of the costs of raw water intake, purification, distributing water, dedicated construction, operation, depreciation, inventory shrinkage and other related costs. The explanatory variables are outputs and input prices. In most previous studies, the delivered water volume is one of the main outputs. In this study, the purified amount of TOC is used as another output, by incorporating it with water volume. The amount of TOC purified from raw water can be calculated by subtracting the average amount of TOC received in the supplied water tests from that observed in the raw water tests. The average amount of TOC in

\textsuperscript{10} There are many substances in drinking water. During purification, TOC is one of the main substances concentrated along with Trihalomethane, water odour, water colour, and so on. However, with the data availability of TOC, the purified amount of this substance is used as a proxy variable for the purified outcome.

\textsuperscript{11} In his study Uragami (2006) assumes that the price of other materials is the numeraire.
supplied water is calculated by arithmetically averaging the amount of it appearing in each test (tests are done around 12 times yearly for each utility). The same method is used to calculate the averaged amount of TOC in raw water.

Input prices consist of capital and labour prices. Capital price is the ratio of capital cost to the fixed tangible assets. The fixed tangible assets are calculated by summing the value of land with depreciation asset and construction in progress, minus accumulated depreciation cost. The labour price can be computed by dividing labour cost by the total number of employed workers.

We also study the factors that may influence cost inefficiency by using the predicted cost inefficiency obtained from the estimation as dependent variable. Independent variables are the subsidy-dependence rate, density of main length expansion, and the quality of raw water in the water source. The subsidy-dependence rate is determined by the ratio of subsidy to operating cost, where subsidy is the sum of local and central government subsidies, the utility’s debt, and the budget from other accountings. Moreover, the density of main length expansion is obtained by dividing the expanded main length by the numbers of the population supplied. All the data mentioned above are available in the Yearbook of Local Public Enterprises (Chiho koeh kigyo nenkan in Japanese), except for the purified amount of TOC, which is obtained from the Japanese Water Works Association (JWWA). A summary of definitions and data is available in Table 1.

### Table 1. Descriptive statistics of variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating cost</td>
<td>Operating cost</td>
<td>$10^6$ yen</td>
<td>2,231</td>
<td>5,535.46</td>
<td>58.81</td>
<td>73275.4</td>
</tr>
<tr>
<td>Waterproduction</td>
<td>Annual volume of water delivered</td>
<td>$10^6$ m$^3$</td>
<td>14.048</td>
<td>32.162</td>
<td>0.217</td>
<td>404.966</td>
</tr>
<tr>
<td>TOC</td>
<td>The purified amount of TOC</td>
<td>mg/liter</td>
<td>0.665</td>
<td>0.890</td>
<td>0.004</td>
<td>11.38</td>
</tr>
<tr>
<td>TOC_raw_water</td>
<td>Amount of TOC in water source</td>
<td>mg/liter</td>
<td>1.320</td>
<td>0.989</td>
<td>0.133</td>
<td>11.8</td>
</tr>
<tr>
<td>Capital price</td>
<td>$Capital \times \frac{Cost}{Tangible\ Asset}$</td>
<td>–</td>
<td>0.061</td>
<td>0.021</td>
<td>0.006</td>
<td>0.172</td>
</tr>
<tr>
<td>Labor price</td>
<td>$Labor \times \frac{Cost}{Number\ of\ employees}$</td>
<td>$10^6$ yen/person</td>
<td>8.175</td>
<td>1.414</td>
<td>4.444</td>
<td>12.762</td>
</tr>
<tr>
<td>Subsidy</td>
<td>$Total\ subsidy \times \frac{Cost}{Operating\ cost}$</td>
<td>–</td>
<td>0.068</td>
<td>0.132</td>
<td>0</td>
<td>1.1</td>
</tr>
<tr>
<td>Density_main</td>
<td>$Main\ length\ expansion \times \frac{Cost}{Supplied\ population}$</td>
<td>m/person</td>
<td>8.41</td>
<td>4.88</td>
<td>1.84</td>
<td>50.10</td>
</tr>
</tbody>
</table>
5. Estimating Result and Discussion

The estimation is done in two separate models, as shown in equations (4) and (5), and the result is available in Table 2.

First, in model A of equation (4), output is the annual delivered volume of water, and the purified amount of TOC is not included as another output. The estimation result shows that the coefficients of delivered water and all input prices are positive and statistically significant with 1% level. This is consistent with the economic theory that cost has the characteristic of monotonic increase with production and input factor prices.

Second, in model B in equation (5), the purified amount of TOC is included as an additional output to water volume. The result demonstrates that the coefficients of all independent variables are positive and significant. This means that consistency with economic theory is maintained. Moreover, the TOC variable’s coefficient is positive, implying that the purified amount of water can influence the cost of operation. This means that those water utilities that purify greater amounts of TOC spend more on operating cost. In addition, considering the variable return to scale, the quadratic form of TOC (i.e., TOC is squared) in the cost function is also estimated. The result of TOC in the quadratic form is not statistically significant.

Table 2. Estimation results of models A and B

<table>
<thead>
<tr>
<th></th>
<th>Half-Normal</th>
<th>Exponential</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(OperatingCost)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(TOC)</td>
<td>0.039***</td>
<td>0.039***</td>
</tr>
<tr>
<td>(A)</td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>ln(Waterproduction)</td>
<td>0.909***</td>
<td>0.909***</td>
</tr>
<tr>
<td>(A)</td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>ln(CapitalPrice)</td>
<td>0.262***</td>
<td>0.262***</td>
</tr>
<tr>
<td>(A)</td>
<td>(0.042)</td>
<td>(0.042)</td>
</tr>
<tr>
<td>ln(Laborprice)</td>
<td>0.271***</td>
<td>0.271***</td>
</tr>
<tr>
<td>(A)</td>
<td>(0.091)</td>
<td>(0.090)</td>
</tr>
<tr>
<td>Constant</td>
<td>4.044***</td>
<td>4.044***</td>
</tr>
<tr>
<td>(A)</td>
<td>(0.801)</td>
<td>(0.792)</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-55.092</td>
<td>-55.092</td>
</tr>
<tr>
<td>σ_u²</td>
<td>0.327***</td>
<td>0.182***</td>
</tr>
<tr>
<td>σ_v²</td>
<td>0.150</td>
<td>0.082</td>
</tr>
<tr>
<td>σ_u² + σ_v²</td>
<td>1.568</td>
<td>0.835</td>
</tr>
<tr>
<td>σ_u²/σ_v²</td>
<td>1.570</td>
<td>0.837</td>
</tr>
<tr>
<td>Likelihood-ratio test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ho: σ_u²= 0</td>
<td>9.97</td>
<td>16.18</td>
</tr>
<tr>
<td>chibar2(01)</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>Prob ≥ chibar2(01)</td>
<td>17.09</td>
<td></td>
</tr>
</tbody>
</table>

Figure in parentheses is value of standard error. Asterisks indicate variables whose coefficients are significant at the 10%(*), 5%(**) and 1%(***) levels, respectively. Sample size is 392

12 The result is available upon request.
To test whether or not the inclusion of TOC variable is acceptable in the model, the log likelihood ratio test is conducted for models A and B, with the null hypothesis that the coefficient of the TOC variable is zero. The null hypothesis is rejected for the cases of both half-normal and exponential distribution\textsuperscript{13}. This indicates that the inclusion of the variable TOC in the cost function is appropriate.

Cost inefficiency is predicted for both models A and B, to compare how the inefficiency score changes with the inclusion of purification. Figure 1 reports the distribution of the inefficiency score of models A and B for the half-normal distribution assumption\textsuperscript{14}. The result shows that some changes occur in the efficiency score of some specific water utilities. Furthermore, a T-test is also done to confirm if there is a difference in efficiency mean between models A and B. The result shows that there is a mean difference between models A and B. In the case in which the purification indicator is considered, the efficiency score improves, as the mean of cost-inefficiency becomes smaller than when it is not included\textsuperscript{15}.

\textbf{Fig. 1 Distribution of cost inefficiency in model A and model B (Half-normal)}

![Distribution of cost inefficiency in model A and model B (Half-normal)](image)

We also observe the level of ranking variation reached after the incorporation of water purification, by taking the top 10 high-ranking utilities in model B as benchmark. As the assumption of distribution on the inefficiency term, half-normal or exponential, may give different results in inefficiency score and ranking, the rank variation between A and B is examined in each distribution model. It is computed by subtracting rank in model A from that in model B, to see how the rank changes. (See Table 3).

From the result, we learn that after the purified amount is incorporated into the estimation model, some utilities improve their rank while the rank of some utilities (i.e. Shimizu, and Numata water authorities) becomes lower. After checking on the purification method used in each utility, the ranking of efficiency improves for some utilities that use sophisticated

\textsuperscript{13} The result is available upon request.
\textsuperscript{14} The result for the exponential assumption is similar. It is available upon request.
\textsuperscript{15} The result is available upon request
techniques in water purification, while the ranking deteriorates for those utilities that use simple purification methods. For example, in the cases of the Shimizu, and Numata water utilities, and probably as a result of the good quality of their raw water, a disinfection-only method, which is relatively cheap, is mainly used in their purification plants. Accordingly, we can explore whether incorporating water purification in the efficiency evaluation may help water utilities that make more efforts in purification to avoid being wrongly evaluated, and may also encourage them to supply a good quality of water.

### Table 3. Top 10 high ranking and variations of ranking between models A and B.

<table>
<thead>
<tr>
<th>Prefecture</th>
<th>Municipalities</th>
<th>Rank</th>
<th>Rank difference</th>
<th>Rank difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Half-normal B</td>
<td>Half-normal (B − A)</td>
<td>Exponential (B − A)</td>
</tr>
<tr>
<td>Tokushima</td>
<td>Matsushige</td>
<td>1</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>Kagoshima</td>
<td>Ibusuki</td>
<td>2</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Hokkaido</td>
<td>Shimizu</td>
<td>3</td>
<td>+2</td>
<td>+1</td>
</tr>
<tr>
<td>Nagashaki</td>
<td>Sazacho</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nagashaki</td>
<td>Shimahara</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Niigata</td>
<td>Tsubame</td>
<td>6</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Shiga</td>
<td>Takashima</td>
<td>7</td>
<td>-6</td>
<td>-6</td>
</tr>
<tr>
<td>Gunma</td>
<td>Numata</td>
<td>8</td>
<td>+2</td>
<td>+1</td>
</tr>
<tr>
<td>Oita</td>
<td>BungoOhno</td>
<td>9</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td>Fukushima</td>
<td>Ishikawa</td>
<td>10</td>
<td>-11</td>
<td>-7</td>
</tr>
</tbody>
</table>

Note: (-) means efficiency ranking improved. (+) means efficiency ranking deteriorated.

The shaded areas indicate water utilities mainly using disinfection-only method in purification plant

### What factors influence cost inefficiency?

Given the characteristics of water, many factors can be considered to affect efficiency. Some such factors may be under the control of the water utilities, but some are environmental factors and are not under the management of the water utilities. To determine which factors may influence cost-inefficiency, an estimation with Tobit regression is done, with cost inefficiency used as the explained variable. For the explanatory variables, we use subsidy-dependence ratio, density of main and amount of TOC in water source, which is used as a proxy variable of quality of water source. The result of the estimation is shown in Table 4.

The subsidy-dependence ratio is obtained by dividing subsidy by operating cost. This indicates to what extent water utilities depend on subsidy for their operation. The result shows a positive impact of subsidy dependence on cost inefficiency. This means that those utilities whose operations depend more on subsidy are seen as performing their service inefficiently. This can be interpreted as a case of the soft budget problem, in that utilities do not operate efficiently when they expect there to be a subsidy to assist them when they meet financial difficulties. However, in the case of water utilities, given their characteristics, it is not clear how to determine whether this is a soft budget problem or not. It is possible that some water
utilities obtain a subsidy because their circumstances make it difficult for them to operate efficiently. For example, the high cost of water intake may result from the water source being far away, or the utility may need to make some capital investment in its facilities due to obsolescence. To determine this it is therefore necessary to check the purpose for which the subsidy is used in each utility.

Table 4. The factors that have an effect on cost-inefficiency

<table>
<thead>
<tr>
<th>Cost-inefficiency</th>
<th>[A]</th>
<th>[B]</th>
<th>[A]</th>
<th>[B]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsidy</td>
<td>0.953***</td>
<td>0.959***</td>
<td>1.020***</td>
<td>1.036***</td>
</tr>
<tr>
<td></td>
<td>(12.58)</td>
<td>(12.64)</td>
<td>(13.74)</td>
<td>(13.79)</td>
</tr>
<tr>
<td>ln (TOC_raw_water)</td>
<td>0.041***</td>
<td>0.004</td>
<td>0.025*</td>
<td>−0.002</td>
</tr>
<tr>
<td></td>
<td>(2.97)</td>
<td>(0.35)</td>
<td>(1.84)</td>
<td>(−0.19)</td>
</tr>
<tr>
<td>Density_main</td>
<td>6.305</td>
<td>5.8828***</td>
<td>5.204***</td>
<td>4.697**</td>
</tr>
<tr>
<td></td>
<td>(3.06)</td>
<td>(2.86)</td>
<td>2.58</td>
<td>(2.30)</td>
</tr>
<tr>
<td>Constant</td>
<td>1.202***</td>
<td>1.2044***</td>
<td>1.111***</td>
<td>1.114***</td>
</tr>
<tr>
<td></td>
<td>(67.68)</td>
<td>(67.71)</td>
<td>(63.82)</td>
<td>(63.26)</td>
</tr>
<tr>
<td>Log-likelihood</td>
<td>134.813</td>
<td>134.471</td>
<td>142.782</td>
<td>138.38</td>
</tr>
</tbody>
</table>

Figure in parentheses is value of t statistics. Asterisks indicate variables whose coefficients are significant at the 10%(*), 5%(**) and 1%(***) levels, respectively. Sample size is 392.

The density of main length expansion is the ratio of main length expansion to the number of the population to which water is delivered. The results show the positive effect of this variable on inefficiency. Therefore, a utility that delivers water in an area where lengthy pipelines are required to deliver water to customers may be vulnerable to inefficiency.

The quality of raw water is represented by the amount of TOC in source water. From the result in Table 4, in model A, the coefficient of the quality of source water is positive and significant. This implies that the quality of water source has an impact on the inefficiency score. This result is similar to Urakami (2006), which found that the type of water source can influence cost. However, in the estimation result of model B, where purification is included, no impact of the quality of raw water is observed. This means that the quality of water source does not influence cost inefficiency when the purified amount of raw water quality is incorporated into the efficiency evaluation.

In brief, in the benchmarking aspect, the regulator may count on the efficiency score or ranking for performance evaluation. Ignorance of water purification can lead to the wrong penalty being imposed on those utilities that undertake extensive purification efforts, and it can also discourage the improvement of water quality in the water service.
6. Conclusion

If water utilities are regulated, their performance can be considered comparatively, and their spending costs must be minimised. As water quality is a huge concern for users, least-cost production must not affect the quality of drinking water. To guarantee good quality of drinking water, this paper argues, by considering the characteristics of water, that it is vital to incorporate the amount of raw water purified into the efficiency evaluation. We prove empirically that the amount purified can influence the operating cost, resulting in a variation in the efficiency score and ranking. Including a purification indicator in efficiency measurement would help to judge more fairly the performance of water utilities, particularly those that use a low quality water source. Moreover, the impact of different qualities of water source on performance efficiency can be controlled. These are the main contributions of this study.

The results suggest that to avoid penalising wrongly, and to encourage an effort at purification, it is crucial to consider water purification in its benchmarking aspect. In this study, due to data availability, only one main chemical substance is used as a proxy variable for the purification index. To calculate the real purification index appropriately, it is crucial to include other chemical substances, and to choose appropriate weights for each of them. This problem is left for future research.

References


**Appendix**

**Distribution of the purified amount of raw water quality**

![Distribution of water quality](image)