Cost Structure of Wastewater and Sludge Treatment in Japan

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1. Introduction

In Japan, sewerage services are owned and managed by municipal governments. The size of companies varies according to the population size of municipalities. At present, a lot of sewerage companies have serious problems. Firstly, sewerage companies are confronted with severe financial conditions. Water demand cannot increase due to population decline and widespread use of water-saving equipment. Therefore, revenue from sewage charge has been gradually decreasing. On the other hand, because sewer facilities are aging and natural disasters (e.g. earthquake, flood) frequently occur, operators need to maintain and repair facilities and take measures against disasters. Accordingly, capital cost has been gradually increasing. Secondly, sewerage companies are facing a labor shortage because of population decline. It is particularly difficult for some small companies to continue to provide sewerage services.

In order to solve these problems, since 2017, the Japanese government has been promoting wide-area consolidation policy to ensure the sustainable management of sewerage systems. In response, the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), which controls sewerage companies, developed a planning manual for wide-area consolidation and sharing of facilities and resources. After that, some companies proceeded with consolidation of facilities within and between companies, but management consolidation such as mergers has not occurred. One reason why management consolidation has not occurred is the lack of evidences of benefits arising from consolidation.

Under these circumstances, this study estimates a translog cost function and examine the economies of scale in wastewater treatment and sludge treatment in Japanese sewerage industry. We estimate cost function using annual data on river basin sewerage authorities treating both sewage and sludge. We investigate whether economies of scale exist in wastewater treatment and sludge treatment and provide evidences regarding the benefits of wide-area consolidation policy.

2. Previous Studies

Numerous studies exist concerning cost structures within the water supply and sewerage industry. Researchers have examined the existence of economies of scale, economies of density, and economies of scope.

Regarding research employing parametric methods, the translog cost function approach is most common (Saal and Parker, 2000; Nakayama, 2001; Nauges and van den Berg, 2008; Satoh, 2012; Mercadier et al., 2016; Maziotis and Molinos-Senante, 2022). While most studies estimated the total cost function, Satoh (2012) estimated the short-run translog variable cost function. He derived the long-run total cost function from the short-run variable cost function and estimated economies of scale in both the short and long run. On the other hand, some studies measured economies of scale by calculating the translog input distance function (Saal et al., 2007; Tanaka, 2021; Tanaka, 2023).

With regard to research employing non-parametric methods, Marques and De Witte (2011) used FDH to verify the existence of economies of scale.

Results concerning economies of scale, density, and scope in the water and sewerage industry vary. Saal and Parker (2000) and Saal et al. (2007) demonstrated diseconomies of scale in the UK water and sewerage services, although Saal and Parker (2000) also demonstrated economies of scope between both services. Nauges and van den Berg (2008) examined cost structure in water and sewerage industry in four countries: Brazil, Moldova, Romania and Vietnam and conducted a comparative analysis of these four countries. They found significant economies of production density existed in the four countries, while significant economies of customer density existed in Moldova, Romania and Vietnam. They also confirmed the existence of economies of scale and economies of scope in Moldova, Romania and Vietnam. Mercadier et al. (2016) demonstrated the existence of strong economies of production density, low positive economies customer density, and slight diseconomies of scale in urban water and sanitation services in Peru. Maziotis and Molinos-Senante (2022) demonstrated that Chile's water industry operated under increasing economies of scale and they found the existence of economies of scope between water and sewerage services. In studies employing non-parametric methods, Marques and De Witte (2011) measured economies of scale using FDH and showed the existence of scale economies for small utilities and the absence of scale economies for the largest utilities in Portugal.

For Japan, some studies evaluated whether economies of scale and density existed only in sewerage works. In Japan, accounting information for water supply and sewerage services is reported separately, enabling researchers to analyze sewerage works alone. Nakayama (2001) showed the existence of economies of density, diseconomies of scale, economies of scope between wastewater treatment and sludge treatment. On the other hand, Satoh (2012), Tanaka (2021) and Tanaka (2023) obtained results indicating the existence of economies of scale.

3. Cost Model

In this study, we estimate the translog cost function based on previous researches. The cost function is expressed in equation (1). As this equation shows, there is two outputs: wastewater treatment and sludge treatment and three input factor prices: labor, capital, and others. The cost function includes a time trend, network and control variables. Previous studies have treated volume of wastewater as an output of sewerage services, whilst volume of sludge has not been considered. Therefore, this study addresses both wastewater treatment and sludge treatment, which are the primary activities of sewerage systems, and defines volume of wastewater and volume of sludge as outputs of sewerage services.

$$
\begin{aligned}
\ln C = \alpha_0 &+ \sum_i \alpha_i \ln Y_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij} (\ln Y_i)(\ln Y_j) + \sum_k \beta_k \ln p_k + \frac{1}{2}\sum_k \sum_l \beta_{kl} (\ln p_k)(\ln p_l) \\
&+ \gamma_N \ln N + \frac{1}{2}\gamma_{NN} (\ln N)^2 + \sum_i \sum_k \delta_{ik} (\ln Y_i)(\ln p_k) + \sum_i \delta_{iN} (\ln Y_i)(\ln N) \\
&+ \sum_k \beta_{kN} (\ln p_k)(\ln N) + \theta_t t + \frac{1}{2}\theta_{tt} t^2 + \sum_i \theta_{ti} t(\ln Y_i) + \sum_k \theta_{tk} t(\ln p_k) + \theta_{tN} t(\ln N) \\
&+ \sum_m \mu_m \ln Z_m \qquad (1)
\end{aligned}
$$

where C: total cost,

Y_i, Y_j: volume of outputs ($i, j = W$ (wastewater), S (sludge)),

p_k, p_l: input factor prices ($k, l = L$ (labor), K (capital), O (others)),

N: network,

t: time trend,

Z_m: control variables,

As with other cost studies, we impose restrictions. Without loss of generality, we impose symmetry in input factor prices, $\beta_{kl} = \beta_{lk}$. A cost function must be homogeneous at degree 1 in input factor prices. Therefore, we impose the following restrictions, $\sum_k \beta_k = 1$, $\sum_k \beta_{kl} = 0$ for all l, $\sum_k \gamma_{Yk} = 0$ for all k. Shepard's lemma implies the input shares (S_k) can be equated to differentiate the cost function with respect to the input prices. The cost share function is expressed as follows.

$$S_k = \beta_k + \sum_l \beta_{kl} (\ln w_l) + \sum_i \gamma_{ik} (\ln Y_i) + \beta_{kN} \ln N + \theta_{tk} t \qquad (2)$$

where S_k: input factor shares ($k = L, K, O$).

The estimated method is SUR (Seemingly Unrelated Regression) by Zellner (1962) for equation (1) and (2). The used share functions are labor and capital.

4. Data

The data used in this study comprises output and costs within the river basin sewerage authorities from 2010 to 2023.

Total costs (C) are the sum of labor, capital and other inputs' costs. Labor costs are the staff salaries. Capital costs are the sum of depreciation costs and interest payments. Other inputs' costs are total operating expenses minus labor and depreciation costs. Output measures (Y_i) considered in this study are volume of wastewater and volume of sludge. As for input factor prices, we consider three input factor prices: labor, capital, and other inputs. Labor price (p_L) is annual total income per person. Capital price (p_K) is defined as the sum of depreciation and interest payments divided by capital stock. As other inputs' price (p_O) cannot be directly observed, the intermediate goods price for the public services in GDP statistics is used as a proxy. Network variable (N) is defined as the length of pipeline.

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