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Abstract

With the data of 831 Japanese water utilities from 1999 to 2008, we used the stochastic cost frontier analysis with a true fixed-effect model in order to estimate the cost efficiency and scale economies. We found that cost inefficiency was approximately 37%. The economies of water delivery volume were observed and found to be remarkably higher for small water utilities than for large ones. Scale economies were also discovered in small water utilities; however, scale diseconomies are likely to be incurred in larger water utilities. The optimal supply population size of a water utility is estimated to be 85,658 consumers, with a water delivery volume of 15.7 million m^3 and a network length of 522 km.

Keywords: Cost Efficiency, Scale Economies, Optimal Size, Japanese Water Utilities

JEL: H11, L38, L95

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1- Introduction

Several countries have adopted the characteristics of successful water utilities to promote performance efficiency, such as imposing incentive-enhancing regulations (e.g. a price cap in the UK), merging together to form larger water utilities (e.g. the case of Dutch water utilities), and permitting the private sector to participate in operating water supply services (e.g. the case of French water utilities).

In Japan, water utilities are operating their services at the municipal level, and most of them are public entities, similar to French water utilities. However, their service operations are independent from each other, and private participation remains low; therefore, it is difficult to exploit private sector know-how. Unlike Japanese water utilities, French water utilities operate their services by outsourcing a part of their operations to a few large private water companies. Since the operations are outsourced to only a few large private companies, the water utilities are likely to operate their service on a large scale, as they can make use of the know-how and experience of the contracted private companies.

With the recent municipal consolidation, the number of Japanese water utilities has decreased gradually, although there were approximately 1,300 Japanese utilities still operating in 2008 and approximately 65% of them provide water services to less than 50,000 consumers. As compared to some other countries, this number is rather high; for example, there are only 21 firms in the UK and 10 in the Netherlands operating water supply utilities. Given that water services consist of various operations (e.g. water withdrawal from its source, water purification, water delivery, fee collection, and maintenance), the operating costs in large-scale water utilities seem to be lower than in small-scale utilities, considering the possible cost saving from scale economies. The higher cost in small-scale water utilities is likely to be caused by their lower rate of capital utilization or higher labour force requirements. An example of higher capital investment in small water utilities is the load factor (the ratio of average water use to peak-time water consumption). Given a lower supply population, the deviation of peak-time water consumption from the average in small-scale water utilities is likely to be higher than that in large-scale water utilities. Therefore, the load factor in small-scale water utilities appears to be smaller than that in large-scale water utilities. This leads to a low facility utilization rate in small-scale water utilities.

However, it is not always true that a larger utility is better. When water utilities become larger, it is possible that their service areas also expand. Water utilities have to bear some costs, such as costs on facilities and water transmission pipeline, if a large number of supply customers do not reside in a specific part of their supply area. As shown in Figure 1, such a region shows an inverted U-shaped relationship between facility utilization rate and transmission pipeline's effectiveness with respect to the supply population size. Moreover, Figure 2 a also indicates an U-shaped variation of total cost and annual employee number and an inverted U-shaped variation of the load factor with respect to population size, implying that there is an optimal water utility size for a specific water supply population.

This study aims to estimate the cost efficiency and scale economies of Japanese water utilities by using data from 831 water utilities from 1999 to 2008 in order to estimate the stochastic cost frontier with a true fixed-effect model. From the results, we also attempt to estimate the optimal size of the supply population in order to minimize cost.

No general conclusion has been drawn regarding the scale economies of Japanese water utilities. Different results have been obtained previously, depending on the estimation sample or method. Kuwahara (1998) used a translog cost function in order to estimate 154 water utilities supplying water to 50,000–300,000 consumers, and the results showed economies of scale in their performance. A similar result was also found in Takada and Shigeno's (1998) study, who used the pooled data of 75 water utilities for the period 1981–1995 in order to estimate the translog cost function by incorporating network length expansion as another output. In contrast, Mizutani and Uragami (2001) used the cross-sectional data of 112 water utilities in 1994 in order to estimate the log-linear and translog functions and diseconomies of scale (i.e. the economy of scale is between 0.85 and 0.96). They also estimated that the optimal size to minimize the average cost is approximately 766,000 consumers.

With respect to cost efficiency, there are some controversial points that need to be controlled for, especially, certain characteristics that water utilities may have and that are likely to affect the efficiency scores. In order to deal with this, several indicators have been used in previous studies, such as quality index (Saal and Parker 2001, Saal et al. 2007), service quality (Lin 2005), and water purification (Horn 2011). However, with stochastic frontier analysis using a true fixed-effect model, originally introduced by Greene (2005), the effects of time-invariant heterogeneity of water utilities can be separated from the efficiency score. Using this method, Filippini, Hrovatin, and Zoric (2008) estimated the cost efficiency of 52 Slovenian water distribution utilities during the 1997–2003 and found that the model is likely to perform better than conventional panel data models.

This study combines the two points, estimations of the scale economies and cost efficiencies, with the newly proposed true fixed-effect models for the case study of Japanese water utilities. There are also two different points from previous studies.

First, for estimating scale efficiencies, we use more recent and broader panel data of Japanese water utilities from 1999 to 2008, whereas Mizutani and Uragami (2001) used cross-sectional data of 1994. The panel dataset would give more information than cross-sectional data since the variation through time of estimation is also considered. Second, as a method to estimate cost efficiency, we use stochastic cost frontier analysis with a true fixed-effect model, originally proposed by Greene (2005). The merit of this method is that it separates the effects of time-invariant heterogeneity of water utilities from the efficiency score. The effects of heterogeneity can be owing to location characteristics (flat or mountainous area), availability of water source, raw water quality, etc. In the conventional panel method, estimators assume that the cost inefficiency is time invariant; with conventional methods, therefore, heterogeneity, in addition to inefficiency, is possibly captured in the efficiency measure. To the best of our knowledge, a true fixed-effect frontier analysis has not been applied in previous studies to estimate cost efficiency in Japanese water utilities.

We find that the average cost inefficiency is more than 37%. Our results also show that water utilities enjoy increasing returns to water delivery volume. However, the effects are likely to be higher in smaller utilities than in larger ones. Moreover, scale economies are also found in small water utilities, whereas scale diseconomies are likely to be incurred in large water utilities. We also found that the optimal size of water utilities is 85,658 consumers for a water delivery quantity of 15.7 million m^3 and a network length of 522 km. This result has the following implication for a water policy: merging water utilities into a larger scale is not always suitable. Water utilities should be of an optimal size.

2- Methodology and Model Specification

In order to estimate the cost efficiencies and scale economies, this study uses stochastic cost frontier analysis methodology. The cost used is the total cost (C), which is the sum of labour costs, capital costs, and other material costs. The cost function comprises water delivery volume (Q), network characteristics (N), labour price (PL), capital price (PK), and other control variables such as network density (NetDen) and time trend (T). Owing to the difficulty in defining the prices of the other materials, which consist of a variety of items, we assume that their prices are constant during the estimation period. Thus, the stochastic cost function can be defined as follows:

$$C_{it} = C(Q_{it}, N_{it}, PL_{it}, PK_{it}, NetDen, T, \beta)\exp(u_{it} + v_{it})$$

The cost function can be transformed into logarithmic form and can be expressed in following manner:

$$\ln C_{it} = \alpha_i + C(Q_{it}, N_{it}, PL_{it}, PK_{it}, NetDen, T, \beta) + u_{it} + v_{it}, \qquad (1)$$

where v_{it} is the noise term, which is assumed to be in normal distribution $v_{it} \sim N(0, \sigma_u^2)$. The notation u_{it} is the non-negative cost inefficiency term. It is the distance from the observed cost to the minimum cost on the cost frontier. In this study, it is assumed to be in truncated normal distribution[1] $u_{it} \sim N(\mu, \sigma_u^2)$. The term α_i denotes time-invariant fixed effect, and β is the vector of the slope parameter.

The cost inefficiency score can be estimated as the ratio of observed cost C_{it} to frontier or minimum cost C^F:

$$Inefficiency_{it} = \frac{C_{it}}{C_{it}^F} = \exp(u_{it}) \tag{2}$$

The cost inefficiency score can be measured on the basis of some conventional models. However, owing to the ability to distinguish between unobserved time-invariant firm-specific heterogeneity and cost inefficiency, this paper uses a true fixed-effect model, which was originally introduced by Green (2005), in order to calculate the cost inefficiency. Separating the effect of firm-specific heterogeneity is likely to make the evaluation more accurate since, in water utilities' performance, different characteristics, such as location from the water source and quality of water, are difficult to control for in the evaluation process owing to lack of information and data.

As the cost function can be specified in several forms, this study estimates two different cost functions: first is the log-linear cost function, and second is the translog cost function, as shown in equations (3) and (4), respectively. However, because the translog cost function is more flexible, we use it as the basic model for estimating cost efficiency and scale economies.

[1] The term, distribution of inefficiency, can be assumed in other commonly used distributions, such as half-normal, exponential, or gamma.

Model 1: Log-linear cost function:

$$\ln \frac{C_{it}}{PK_{it}} = \alpha_i + \beta_Q \ln Q_{it} + \beta_N \ln N_{it} + \beta_{PL} \ln \frac{PL_{it}}{PK_{it}} + \gamma_{Net} NetDen + \gamma_T T + u_{it} + v_{it} \quad (3)$$

Model 2: Translog cost function:

$$\begin{aligned} \ln \frac{C_{it}}{PK_{it}} = {} & \alpha_i + \beta_Q \ln Q_{it} + \beta_N \ln N_{it} + \beta_{PL} \ln \frac{PL_{it}}{PK_{it}} + \frac{1}{2}\beta_{Q,Q} \ln Q_{it} \ln Q_{it} + \\ & + \frac{1}{2}\beta_{N,N} \ln N_{it} \ln N_{it} + \beta_{Q,N} \ln Q_{it} \ln N_{it} + \beta_{PL,PL} \ln \frac{PL_{it}}{PK_{it}} \ln \frac{PL_{it}}{PK_{it}} + \\ & + \beta_{PL,Q} \ln \frac{PL_{it}}{PK_{it}} \ln Q_{it} + \beta_{PL,N} \ln \frac{PL_{it}}{PK_{it}} \ln N_{it} + \gamma_{NetDen} NetDen + \gamma_T T + u_{it} + v_{it} \end{aligned} \quad (4)$$

In addition to cost efficiency, we also estimate the output density and economies of scale. The output density determines how the cost reacts to the increase in output Q by holding the network characteristics fixed. It can be calculated through $E_{OD,}$ as shown in equation (5). If E_{OD} is more than 1, it indicates the existence of the economy of output density, implying that the average cost decreases when the output increases. Moreover, the economies of scale measure the reaction of cost to the proportional increases of output Q and network characteristics (N). It can be calculated through E_S, as shown in equation (6). If E_S is more than 1, it indicates the existence of economies of scale, and if it is less than 1, it indicates the existence of diseconomies of scale. Table 1 summarizes the calculations of output density and economies of scale that are available from our estimation models.

Measurement of output density:

$$E_{OD} = \left(\frac{\partial \ln C}{\partial \ln Q} \right)^{-1} \quad (5)$$

Measurement of economies of scale:

$$E_S = \left(\frac{\partial \ln C}{\partial \ln Q} + \frac{\partial \ln C}{\partial \ln N} \right)^{-1} \tag{6}$$

3- Data Description

Most water utilities in Japan are under the public authority of towns, cities, prefectures, and cooperatives. Following the municipal consolidation in recent years, the number of Japanese water utilities gradually decreased to approximately 1,300 in 2008. Out of these, this study uses the observations of 831 utilities from 1999 to 2008 for the estimation, excluding those of the cooperatives and other utilities that merged during the 1999–2008 period. The reason for this is that it is difficult to determine their cost structures, since cooperatives operate their services in conjunction with the other utilities. Moreover, complete data of the merged utilities for the entire 10-year period is not available for creating a balanced panel. Total cost (TC) is the sum of the costs of capital, labour, and other materials and price of labour (PL) is the annual basic salary of an employee. The price of capital (PK) is the capital cost divided by the length of transmission pipe extension, which is a proxy of the capital stock. Output (Q) is the annual volume of water delivery, and network (N) characteristics represent the annual length of the transmission pipe extension. Besides the basic variables for cost function, we also control for other variables that may influence cost, such as network density and time trend. Network density is the ratio of transmission pipe length to supply population. Supply population refers to the total customers of each water utility. All data are available in the annual Yearbook of Local Public Enterprises (*Chiho koeh kigyo nenkan* in Japanese). Table 2 presents the descriptive statistics.

4- Estimating Results

The estimations were made using the stochastic cost function with a true fixed-effect model[1]. The cost function is in both log-linear form (Model 1) and translog form (Model 2). Table 3 presents the results.

Initially, we obtain the statistically significant and positive effects of output coefficients in both models, which hold the non-decreasing characteristics of output in cost function. This is consistent with economic theory. Subsequently, in Model 2, although the coefficient of squared N is not significant, we determine that the coefficient of squared Q is positive and significant, indicating that cost is a convex function of Q. Moreover, the slopes of labour price (PL) are positive and statistically significant for both models, whereas the slope of the squared labour price is negative and significant in Model 2. This is consistent with the theoretical characteristic of a cost function that is non-decreasing and a concave function of the factor's price. Network density, which is the ratio of network length to number of consumers, is negative. This implies an increase in the cost of supplying water for water utilities that supply water with short pipeline networks to a large number of consumers. This is likely to negate any possible cost saving on water

[1] LIMDEP 9.0 Software is used for the estimation.

distribution. However, as argued by Torres and Morrison (2006), this may occur because, although short pipelines may save distribution cost, more cost is possibly required for multiple complex connections, pressure, or maintenance problems. The time trend is negative and significant, which means that the cost decreases over a period of time, for example, through progress in technology.

Table 4 reports the descriptive statistics of cost inefficiency. We found that the average cost inefficiencies for both models are almost equal: 40.4% for Model 1 and 37.9% for Model 2. These percentages are twice of those obtained by Nakayama (2007), that is, approximately 20%. Nakayama (2007) used the panel data for water utilities in Shiga, Kyoto, and Osaka from 1991 to 2003 in order to estimate the Cobb-Douglas cost function with some alternative conventional panel models, but without a true fixed-effect model. By using a true fixed-effect model, this study gives a different inefficiency score because the effects of heterogeneity of water utilities on the efficiency score are controlled. From the estimation result, we find that there is more room to improve the cost efficiency score by introducing proper incentive-enhancing schemes.

Table 5 reports the average output density and scale economies. The output density for both models are considerably high, that is, approximately 5.3, which means that for a given network length, an increase of water delivery quantity can substantially reduce the average cost. In addition, when the water delivery volume increases, it is likely that the network length also needs to be increased; the cost reaction to these proportional increases can result in scale economies. The scale economies are slightly less than 1 (i.e. 0.99) for Model 1 and more than 1 (i.e. 1.03) for Model 2, showing that, on an average, it is likely that the phenomenon of constant returns to scale is exploited. However, based on Figures 3 and 4, which represent the relationships of network length and water delivery volume with scale economies, we observe that scale economies decrease with network length (N) and water delivery quantity (Q). A scale economy value of more than 1 covers a large share of water utilities (see Table 6), mostly in small utilities. This value turns out to be less than 1 after the size of N and Q crosses a specific threshold.

The threshold is the point that turns economies of scale to diseconomies of scale (i.e. the point where scale economies become 1), and, theoretically, this is the optimal size for minimizing average cost. Thus, the optimal size of N and Q can also be determined at the threshold. From the estimated parameters, we can calculate the scale economies for each water utility. We average the values of Q and N of the utilities whose scale economies equal 1. We find that the optimum size to minimize cost is at the point where Q equals 15,718 thousand m^3 and N equals 522 km. However, in practice, the water delivery quantity and network length are difficult to adjust because they may mostly relate to consumer water usage or density, rather than to management of water utilities. Nevertheless, water utilities can adjust the supply population, for example, through utility consolidation or fragmentation[1]. Thus, from the optimal N and Q, we estimate the optimal population size in order to minimize the average cost with equation (7). Equation (7) is a

[1] In order to find the optimal size of the supply population, the number of consumers should be included in estimation models, as was done in Torres and Morrison (2006) or Filippini, Hrovatin, and Zoric (2008). However, due to the high correlation between water delivery volume and population size, this study does not include population size in the estimation models.

panel regression with a fixed-effect model, which determines the relationship of N and Q with supply population size (POP).

$$\ln POP = \underset{(0.0392)}{3.64} + \underset{(0.0044)}{0.26} \ln N + \underset{(0.0058)}{0.63} \ln Q \qquad \text{Overall } R^2 = 0.96 \tag{7}$$

We found that the optimal size of supply population is 85,658 consumers. This is approximately 9 times lower than the finding of Mizutani and Uragami (2001); according to them, the optimal size was approximately 766,000 persons. However, because Mizutani and Uragami (2001) used cross-sectional data of only 112 water utilities, our finding gives a new optimal size based on a new, broader, and longer dataset. Moreover, we found that our results are consistent with those of Filippini, Hrovatin, and Zoric (2008) for the case of Slovenian water utilities, in terms of scale economies and optimal supply population size. Owing to the similarity between Japanese and Slovenian water utilities' performance (i.e. public entity in form of natural monopoly), we found the following two common points for both the case studies: increasing return to scale in small-scale water utilities and optimal size for water utilities. From these results, we can intuitively say that public water utilities should merge and become an appropriate size, rather than being too small or too big. However, the problem is the manner in which the optimal size must be determined, since for water utilities, optimal size can be related to some factors such as geographical characteristics and socio-economic status of water users. Moreover, although the optimal size can be determined by the manager, it may be difficult to reach this optimal size without a proper incentive scheme.

5- Conclusion

Most Japanese water utilities are public entities and operate at the municipal level, independent from each other and in the form of a natural monopoly. There is a remarkable price gap among these utilities. This gap results not only from the different characteristics of the area but also, possibly, from performance efficiency. Moreover, the size of most of the water utilities remains small.

This study used the panel data of 831 Japanese water utilities for the period between 1999 and 2008 in order to estimate the cost efficiency and scale economies with log-linear and translog cost functions. By using stochastic cost frontier analysis with a true fixed-effect model, we separated the effects of heterogeneity of water utilities from the efficiency score, as argued in some previous studies.

The results showed that the average cost inefficiency is rather high, that is, approximately 37%. Thus, it is crucial to have an incentive scheme for reducing cost and improving performance in the future. Moreover, small utilities are found to have higher output densities and scale economies than large ones. We also found that an optimal water utility is one with approximately 85,658 consumers, an annual delivery volume of approximately 15,718 thousand m^3, and a network length of approximately 522 km. Since most water utilities are still smaller than this optimal size, consolidation to create larger water utilities must be encouraged.

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Table 1: Measurement of Output Density and Scale Economies

Model	Output Density	Scale Economies
Log-linear	$1/\beta_Q$	$1/(\beta_Q + \beta_N)$
Translog	$1 \Big/ \left[\begin{array}{l} \beta_Q + \beta_{Q,Q}(\ln Q) + \\ + \beta_{PL,Q}(\ln PL) + \beta_{Q,N} \ln N \end{array} \right]$	$1 \Big/ \left\{ \begin{array}{l} \left[\beta_Q + \beta_{Q,Q}(\ln Q) + \beta_{PL,Q}(\ln PL) + \beta_{Q,N} \ln N\right] + \\ \left[\beta_N + \beta_{N,N}(\ln N) + \beta_{PL,N}(\ln PL) + \beta_{Q,N} \ln Q\right] \end{array} \right\}$

Table 2: Descriptive Statistics

Variable	Definition	Mean	Standard Deviation	Minimum	Maximum
TC	Total cost (10^9 yen)	1.883	5.483	0.025	89.8
Q	Water delivery volume (10^3 m^3)	11,852.38	31,813.1	75	528,833
N	Transmission pipe length extension (10^3 m)	416.2	680.6	12.1	9,197.4
PK	Capital price (yen/m^3)	1,804.1	1,088.3	98.6	23,107.6
PL	Labour price (10^3 yen)	4,586.7	3,228.1	145.1	58,572
NetDen	Network density (m/person)	7.9	4.9	1.01	67.2
Pop	Supply population (person)	88,452	230,243	1,600	3,684,645

Table 3: Estimating Results of Stochastic Cost Functions

Coefficient	Model 1	Model 2
β_Q	0.186*** (0.004)	0.183*** (0.024)
β_N	0.817*** (0.009)	0.645*** (0.038)
β_{PL}	0.201*** (0.002)	0.776*** (0.021)
$\beta_{Q,Q}$		0.017* (0.009)
$\beta_{N,N}$		0.020 (0.015)
$\beta_{Q,N}$		-0.006 (0.012)
$\beta_{PL,PL}$		-0.118*** (0.004)
$\beta_{PL,Q}$		-0.123*** (0.004)
$\beta_{PL,N}$		0.115*** (0.006)
γ_{NetDen}	-0.003*** (0.0005)	-0.007*** (0.0006)
γ_T	-0.001** (0.0006)	-0.002*** (0.0006)
$\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$	2.63*** (0.027)	2.47*** (0.026)
$\lambda = \sigma_u / \sigma_v$	26.93*** (1.666)	26.34*** (1.904)
Observation number	8310	8310

Note: Standard errors are shown in parentheses. ***, **, and * denote p-values at significance levels of 1%, 5%, and 10%, respectively

Table 4: Descriptive Statistics of Cost Inefficiency

	Mean	Standard Deviation	Minimum	Maximum
Model 1	1.404	0.163	1.192	4.051
Model 2	1.379	0.160	1.172	6.479

Table 5: Average Output Density and Scale Economies

	Model 1	Model 2
Output density	5.37	5.42
Scale economies	0.99	1.03

Table 6: Summary of Scale Economies

	Number of Utilities	(%)
Increasing returns to scale	6,573	(79.0%)
Constant returns to scale	754	(9.0%)
Decreasing returns to scale	983	(11.8%)

Figure 1: Variation of facility utilization rate and percentage of transmission pipe utilization's effectiveness (sample: 831 water utilities, year 1999-2008)

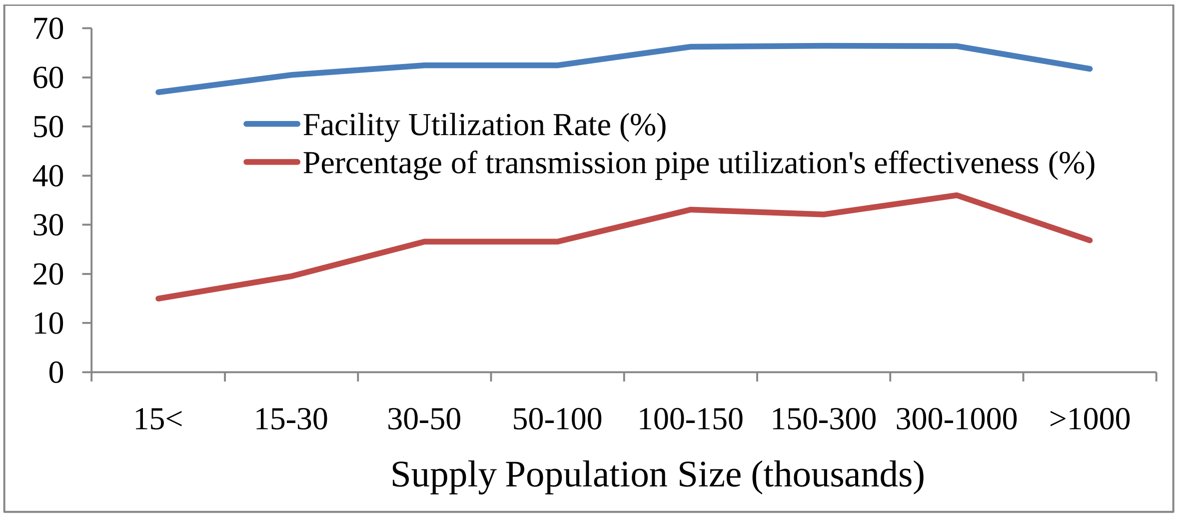

Figure 2: Variation of number of employees, load factor, and total cost with respect to the supply population size (sample: 831 water utilities, year 1999–2008)

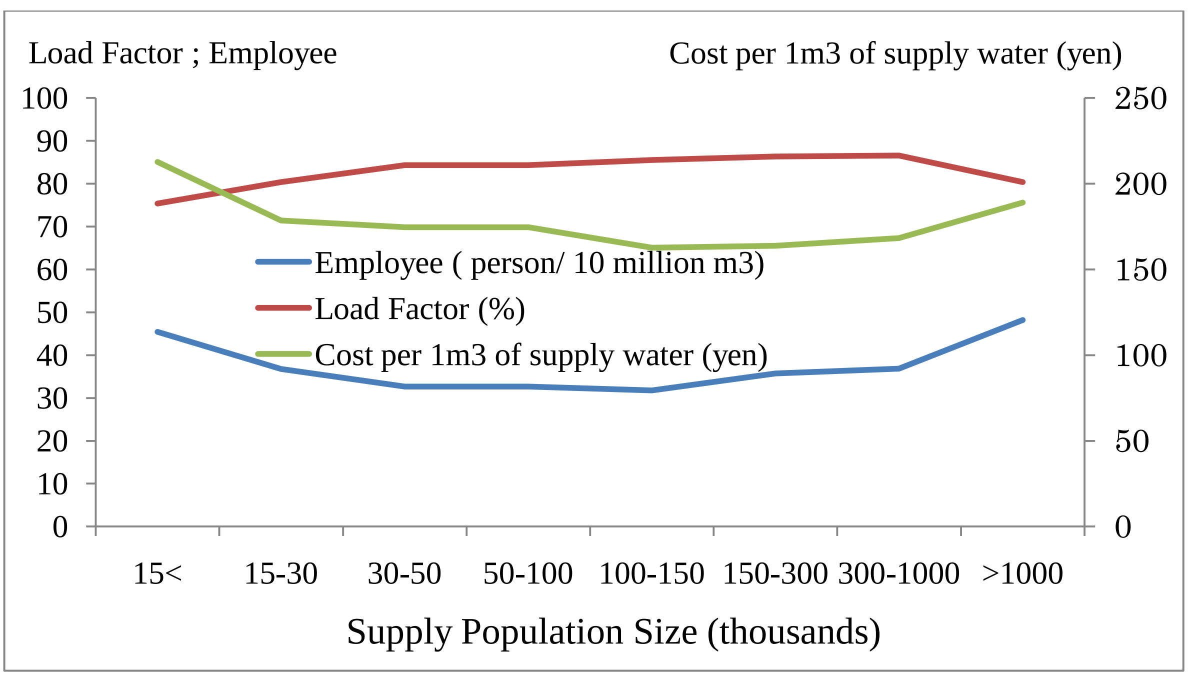

Figure 3: Relationship between network characteristics and scale economies

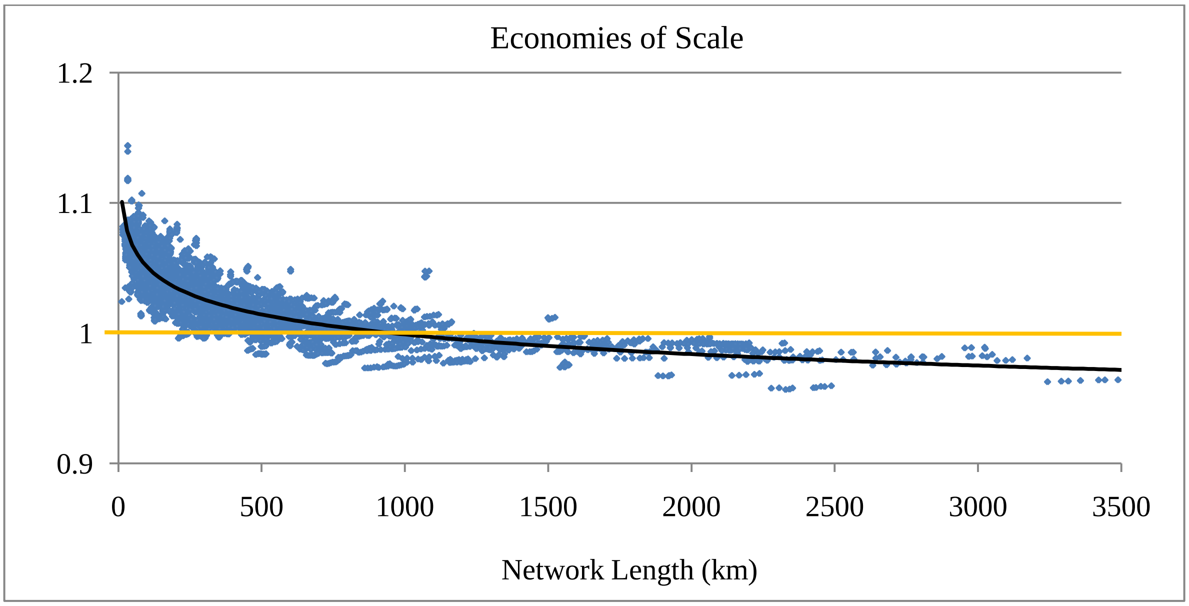

Figure 4: Relationship between water delivery volume and scale economies