Desalination and Water Treatment
www.deswater.com

1944-3994 / 1944-3986
doi: 10.5004/dwt.2010.1961

18 (2010) 327–340
June

Cost analysis of urban water supply and waste water treatment processes to support decisions and policy making: application to a number of Swedish communities

Madelene Malmsten[a], Demetris F. Lekkas[b,*]

[a]*KTH – Royal Institute of Technology Stockholm, SE-100 44 Stockholm, Sweden*
[b]*Department of Statistics and Actuarial-Financial Mathematics, University of Aegean, 83200 Karlovassi, Samos, Greece*
Tel. +30 227 308 2357; Fax +30 227 308 2309; email: dlekkas@env.aegean.gr

Received 15 April 2010; Accepted 21 April 2010

ABSTRACT

An econometric model has been developed that represents the cost structure of water supply and waste water treatment in an urban area. This paper proposes a method to capture the financial characteristics of the underlying organisation and addresses the steps and the conceptualisation in order to create a cost structure for municipal water utilities. The estimation procedure is based on a multivariate regression approach and the cost structure is represented by a parametrical expression (cost function). This function has been used for the purpose of analysing the observed system in terms of efficiency, technology, capacity, financial state etc. In the mathematical formula the estimated parameters relate certain system input components to costs, which are important in order to understand the key drivers. An empirical analysis is undertaken for a number of utilities in Sweden.

Keywords: Cost analysis; Urban water supply; Mathematical modelling; Cost structure; Cost function; Scale economies

1. Introduction

In many parts of the world a large percentage of the water and wastewater infrastructure is reaching its end of life, as it was first developed and installed at the beginning of the 20th century. The infrastructural changes in urban areas may be one of the 21st century's biggest challenges (Clark et al., 2002). Furthermore the supply of water to public and the treatment of wastewater should preferably be performed in an effective and environmentally friendly way (Lekkas et al., 2008). Additionally, new standard requirements affect the supply and treatment plants in multiple ways, i.e. technologically, organisationally and economically. The changes may well mean increased supply and treatment costs, leading to higher service rates to customers.

There are many drivers behind the ongoing developments and changes in water resources, however the economic viability of the water utilities is a prerequisite particularly as private investors have shown their interest in the industry. The extent of investors' involvement varies from country to country. In England, the water and wastewater facilities are privately owned and are mainly regulated by the The Office of Water Services (OFWAT) authority. In France, the individual communities are responsible for controlling the facilities and many of the communities (75%) have chosen to let private actors run the operations (Thomasson, 2003). Quite the opposite

*Corresponding author.

holds for Greece, where most of the facilities (60–75%) are municipally owned and controlled (E.Y.D.A.P, 2006). In Sweden, there are a few privately owned facilities but most of the organisations are operated by the regional municipality (Thomasson, 2003).

Among other issues, the Water Framework Directive stipulates cost analysis of the water and wastewater services. The analysis should include estimations of the economic impacts that water and wastewater services have on the environment as well as studies of financial costs of the water and wastewater services (Camp Dresser & McKee Ltd, 2004). It is clear that not only regulators are interested in the analysis of costs but also water and wastewater organisations want to have information about their costs in order to control and plan their activities. If the cost is correctly estimated and analysed then an appropriate price for the supplied service can be defined. Cost recovery is the main goal of water pricing in order to ensure the sustainability and the quality of water services.

Apart from this direction, cost structure analysis is also important concerning environmental and social welfare aspects. In periods of increasing water resources scarcity, it may be relevant to assess the efficiency of a water supply system in the direction of detecting and reducing inefficiencies (technical or economic) and of reducing operational costs by merging with other water utilities.

The process of identifying and capturing a cost structure a system is not necessarily the same as to capture the actual costs raised by the system. The cost structure should preferable be seen as (monetary) "behaviours" of the underlying technology, which one would like to measure or estimate. For technological and structural characteristics to be captured in terms of costs, one can possibly identify critical components and their interrelations.

The selection of a mathematical formula and the inclusion of specific variables is based on the examined venture and the available information. A water and wastewater organisation is complex as it incorporates many components that interrelate to each other and it has been formalized based on certain rules, organisational plans, the topography and the characteristics of the city that is being supplied. A structural representation of any water and wastewater system can become complicated, still a good representation may limit the risk of missing or overlooking critical parts of the system.

The cost structure of a system can be analysed in order to assess efficiencies and inefficiencies in the system. The information obtained from the analysis can be useful in a number of applications, e.g. when planning new construction and/or replacement projects. It can be seen as a complement to actual cost estimations.

(a) When pricing the water and wastewater services.
(b) When evaluating the financial situation of a system (or an entire industry).

Usually actual costs of complex organisations and ventures are more accurately estimated by using bottom-up procedures. This means that the costs of activities are estimated separately and added up to a total cost. Ramirez (2001) has used the bottom–up approach to estimate total cost of a water and wastewater utility. He estimated the costs for each activity of the water and wastewater system. Each part of the system was evaluated in terms of costs; the investments of the constructions and the operational costs of the system. The model developed by Ramirez (2001) has been practically implemented and is a part of the research programme "Sustainable Urban Water Management", by CIT Urban Water Management AB in Sweden.

The objectives of this paper are to examine how an econometric model can be created and designed to understand and describe how to assess a cost structure of the water and wastewater services. This includes forming an understanding and an opinion about which variables should be included in a model. In this paper a financial analysis, by applying the direct cost approach has been performed. Direct costs are the investments and operating costs incurred by the responsible agency in production of the service (Gordon, 2005). The analysis in this study involves an application of econometric tools on the financial data.

2. Water and wastewater utilities and costs

Water can be seen as a final product and/or a service that is provided to "water customers" having certain demand characteristics (Kim, 1995). In this paper, water is regarded as a service rather than a product. Water can be considered as *output* from the production process to the water distribution system and it is later in its untreated form that can be can considered as *input* to the purification system (wastewater treatment plant).

First, water is produced and distributed through the distribution network to connected customers. Then, the water is transformed to wastewater and finally the wastewater is collected through wastewater network and transferred to the wastewater treatment plant for the purification process. For a joint water and wastewater utility the resulting *production output* is therefore the provided *water and wastewater service*. The "service" refers to the procedure of supplying water, collecting and treating wastewater. Numerically, as will be shown in the mathematical framework, volumes of supplied water and treated wastewater are the production outputs, i.e. they are variables that represent the service.

The water industry is capital-intensive, second to the energy sector (Agthe et al., 2003), and its capital stock consists of network pipelines, specific equipment facilities and trained personnel. Salaries together with electricity represent the largest groups of operational expenses. Expenses that vary in line with the volume of produced water are for example expenses for energy (in pumping) and chemicals (for treatment). Due to modern technical interventions and improvements the cost of electricity is expected to be reduced in the coming years.

There are a number of characteristics and technological features of the water industry that pose difficulties in analysing and providing a representative and comparable cost function of water and wastewater services (Barucq et al., 2006; Garcia and Thomas, 2001; Cubbin, 2004):

- Origin of the resource; different costs for treating groundwater or surface water.
- Technical characteristics; distribution process, size of the utility service area, population per mile of water pipeline.
- Joint account for water and wastewater services – assumptions have to be made in order to distribute expenses between the two services, introducing a margin of error in the reassignment of costs.
- Source of investments not always clearly identified or precisely estimated—private, municipality, region, State and/or European fund.
- Group of actors involved in services management.
- Differences in production factor costs among public and private operators are a result of national features and cannot easily be interpreted in an international system.

The British regulator OFWAT makes an important observation (Finn, 2006; report 2005–2006) concerning capital charges, indicating that there are different accounting practices between water companies. This may complicate the procedure of making comparisons of costs between companies and communities. In Sweden, according to SWWA Department of Development (report 2007–2013) the capital costs are in most cases reported as an entirety cost, i.e. no separate accounting for each separate part, such as the water distribution network. Furthermore SWWA has introduced a theoretical capital cost for the pipe network based on the average age of the pipe system, its structure, climate conditions and topography. In order to represent and capture the heterogeneity of the modelled system, variables that represent capital stock (production and treatment plants, pumping stations and distribution networks) should be incorporated in the cost function (Garcia and Thomas, 2001).

As been mentioned in the introduction, it is important for the reader to understand the different concepts of cost structure representation and cost estimation. The terms "cost model" or "cost function" imply a model that captures the technological and structural characteristics of a system, in terms of costs. The model can be used for the purpose of studying in what direction and to what extent the costs of a business get affected by a system change. For example, by holding a representative mathematical cost structure of a system and by knowing that the marginal cost depends on the production quantity, there can be enough information in order to calculate numerically how the marginal cost gets affected by the production quantity. A well behaved cost model can also capture how other components affect the marginal cost, e.g. how prices and operational variables (distance, network density, etc). Therefore an important step in the analysis is to identify the critical components. In this study unit costs have been recognized as critical components, e.g. cost/hour (labour force), cost/kWh (energy), cost/material index (material) and cost/capital index (capital). As will be shown in the empirical study, these unit costs are introduced into the cost model but they are expressed as unit *prices* instead: price/hour, price/kWh, price/material index and price/capital index. Principally, an assumption has been made that a price can be assigned at service provided by the water and wastewater utilities. The prices are fixed and as consequently the corresponding costs (Stone and Webster Consultants Ltd, 2004).

Except prices, there are other components that affect the costs for the water and wastewater utilities: structure and length of the pipe networks, the type of treatment plants, population density (customer density), the type of customers' distribution in terms of different uses (industrial users, domestic users and public users), the quality of the water, etc.

Additionally, operational variables that might be difficult to control numerically can be treated as dummy variables (takes values 0 or 1). For example, a dummy variable is included in the model and takes the value 1 if the corresponding utility distributes chemically treated water and the value 0 otherwise. Féres and Reynaud (2006) have included dummy variables that control for licence agreements (yes/no) and environmental regulations (yes/no). Urakami (2005) has included a dummy for dam water and one for groundwater. Martins et al. (2006) use one dummy for ownership. Bottasso and Conti (2003) constrain their mathematical function by including a dummy for wastewater (yes/no).

It is desirable to construct a model that captures all of these components even though it is not always easy. As mentioned earlier it might be necessary to separate the services in different parts and construct models for these individual parts. However, complications may arise when there is need to represent the business with a single model, which may be the case when a cost structure for the total industry is required. For example, Hanemann (1998) states that the economic connection between water and wastewater can be neglected if the systems are analysed separately: "The systems may involve different technological choices, but the choices are inter-dependent: the costs of water supply are likely to affect decisions on waste disposal, just as the costs of waste disposal are likely to affect decisions on water intake and use." Table 1 is taken from OFWAT and contains the critical components that have been used for benchmarking the English water and wastewater firms. These critical components represent expert judgments of potential cost drivers in the industry. A few of these components have been used in the empirical study.

The water and wastewater technology can be better understood if it is modelled as a multiple output production process (Kim, 1995). The multiple outputs can be the supplied water and treated wastewater. If the outputs are regarded as supplied water and treated wastewater to customers, i.e. water to industry, households and public uses, focus can placed on a customer analysis.

The economic modelling of the production processes using a multi-product cost function provides indications on the performance and efficiency of an existing system but also with respect to future changes. In that way, one can understand if the existing systems can handle the growing changes or if the systems are in need for re-investments. Efficiency can be measured in terms of e.g. economies of scale, economies of production output density, economies of customer density and economies of scope.

3. Econometric analysis of cost

3.1. Cobb–Douglas production function

An establishment, in this case a water and wastewater utility, producing water (output 1) and treating wastewater (output 2) can be represented by the use of certain N inputs, e.g. capital, labour, electricity and material (Hanemann,1998). The price of input k (where $k = 1,..., N$) is denoted by w_k and the amount of the input k is denoted by x_k. The total cost of production and treatment for the water and wastewater utility is then given by the function

$$\mathrm{TC} = \sum_{k=1}^{N} w_k x_k = w_1 x_1 + w_2 x_2 + \cdots + w_N x_N. \quad (1)$$

Table 1
Potential cost drivers, based on OFWAT's Appendix 1 in report 2005–2006.

Operational expenditure	Explanatory variables included in the model	Capital maintenance expenditure	Explanatory variables included in the model
Water distribution model (log model)	Resident population (scale) Small/big mains (cost drivers)	Water distribution model (log unit model)	Length of main (scale) Connected properties/length of main (cost driver)
Water resources and treatment model (linear model)	Resident population (scale) Supplies from boreholes (cost drivers) Number of sources Distribution input	Water distribution model (non-infrastructure) (log unit model)	Pumping station capacity (scale) Tower and service reservoir capacity Ratio of storage capacity to pumping station capacity
Water power model (log linear model)	Terrain Power Pumping head and distribution input (cost drivers)	Water management and general model (log model)	Billed number of customers (scale) Billed properties that are non-household (cost driver)
Water business activities model (log linear model)	Billed properties (cost driver)	Sewage treatment model (log unit model)	Total load (scale) Load treated by sewage treatment works
Sewerage network (incl. power) model (log linear model)	Sewer length (scale) Area of sewer district Resident population Holiday population	Sewage infrastructure model (log unit cost model)	Total length of sewers (scale) Combined sewer overflows (cost driver)
Large sewage treatment works model (log linear model)	Load, type of treatment and effluent consents (cost drivers)		

The volume of produced and treated water/wastewater by the utility at a specific unit of time is denoted by y. It is relevant to relate the output y to the N inputs in order to get the production function for the utility. The Cobb–Douglas production function was one of the most frequently used production functions in the applied field of water supply and treatment in the 1960s and 1970s. The Cobb–Douglas function has however been abandoned in favour for other production models, such as the constant elasticity of substitution (CES) production function. In order to understand the concept of a cost function that includes prices and outputs rather than production quantity the Cobb–Douglas production function is used here as the CES production function has a more complex parametric structure.

The Cobb–Douglas production function is given by the following expression:

$$y = A \cdot \prod_{k=1}^{N} x_k^{a_k} = A x_1^{a_1} x_2^{a_2} \cdot \ldots \cdot x_N^{a_N} \quad A > 0, \quad a_k > 0, \quad k = 1,\ldots,N, \tag{2}$$

where A, a_1, ..., a_N are parameters that could be given or that should be estimated, and depend upon the relationship between the output and the inputs.

If a water and wastewater utility can be represented by a Cobb–Douglas production function and the utility wants to minimize its total costs, this can be presented by the following equation (where x_1, ..., x_N are the optimal input levels):

$$\min \mathrm{TC} = \sum_{k=1}^{N} w_k x_k \text{ subject to } y = A \cdot \prod_{k=1}^{N} x_k^{a_k}. \tag{3}$$

Without questioning the microeconomic proofs referred to in the notations of Hanemann (1998), a set of functions, *long-run conditional input demand functions*, have been introduced which give the optimal choice of inputs:

$$x_k = g^k(w_1, w_2, \ldots, w_N, y) \quad k = 1, \ldots, N. \tag{4}$$

The g^k function represents the demand for input x_k. The *total cost of production for the utility at the optimum,* is given by the following equation:

$$\mathrm{TC}(w_1, w_2, \ldots, w_N, y) = \sum_{k=1}^{N} w_k g^k(w_1, w_2, \ldots, w_N, y). \tag{5}$$

If there is interest in the short-run total cost of production at the optimum, the capital input should be fixed at a level of x_N, where N stands for the input N (=capital). The other 1, ..., N 1 inputs are variables (e.g. labour, electricity and material). The total cost is denoted by TC, the total variable cost by TVC and the total fixed cost by TFC ($=w_N x_N$).

$$\begin{aligned} &\mathrm{TC}(w_1, w_2, \ldots, w_N, x_N, y) \\ &= \mathrm{TVC}(w_1, w_2, \ldots, w_{N-1}, y) + w_N x_N \\ &= \sum_{k=1}^{N-1} w_k g^k(w_1, w_2, \ldots, w_{N-1}, x_N, y) + w_N x_N. \end{aligned} \tag{6}$$

In the above expression, the short-run-case provides an estimate of the demands for inputs conditioned on the levels of the fixed inputs, i.e. $x_k = g^k$ (w_1, w_2, ..., w_{N-1}, x_N, y) for $k = 1,\ldots,N$. In the long-run-case, the demands for inputs are conditioned on the prices of the fixed inputs, i.e.

$$x_k = g^k (w_1, w_2, \ldots, w_N, y) \qquad \text{for } k = 1,\ldots,N.$$

The cost function TC(w_1, w_2, ..., w_N, y) for $N = 2$ in the cases of a Cobb–Douglas production function can be derived with the use of Shephard's lemma (Andersson, 2007):

$$\begin{aligned} &\mathrm{TC}(w_1, w_2, y) = \sum_{k=1}^{2} w_k g^k(w_1, w_2, y) \\ &= (a_a + a_2) \left(\frac{y}{A}\right)^{\frac{1}{a_1+a_2}} \left(\frac{w_1}{a_1}\right)^{\frac{a_1}{a_1+a_2}} \left(\frac{w_2}{a_2}\right)^{\frac{a_2}{a_1+a_2}} \\ &\text{where } x_1 = g^1(w_1, w_2, y) = \left(\frac{y}{A}\right)^{\frac{1}{a_1+a_2}} \left(\frac{a_1 w_2}{a_2 w_1}\right)^{\frac{1}{a_1+a_2}}, \\ &x_2 = g^2(w_1, w_2, y) \end{aligned} \tag{7}$$

The same approach can be followed for the CES production function. The resulting cost function is

$$\begin{aligned} &\mathrm{TC}(w_1, w_2, y) = \frac{y^{1/\mathrm{m}}}{A} \left(\mathrm{d}_1^{\mathrm{s}} w_1^{\mathrm{s\,r}} + \mathrm{d}_2^{\mathrm{s}} w_2^{\mathrm{s\,r}}\right)^{1/\mathrm{s\,r}} \\ &\text{where } \mathrm{m} > 0, \mathrm{s} \equiv \frac{1}{1+\mathrm{r}} > 0, \end{aligned} \tag{8}$$

where the δ are share parameters, ρ depends on the degree of substitutability of the inputs and A and μ depend upon the units in which the outputs and inputs are measured (www.minneapolisfed.org/research/prescott/macro_theory/Lectures/CESProdFn.pdf).

3.2. Transcendental logarithmic cost function

Nowadays, the transcendental logarithmic (Translog) cost function (Christensen et al., 1971) is often used by researchers for the purpose of representing the production technology (see for example, Feigenbaum and Teeples, 1983; Féres and Reynaud, 2006; Martins et al., 2006). The Translog cost function may be interpreted as a second order Taylor series approximation to the true cost function rather that the function itself. It is often mentioned in the literature of water supply costs, but its practical use is not restricted to the water industry and it has been applied within other industries such as the banking industry and the electricity industry. The Translog cost function has the advantage of being flexible with only few restrictions on its input data. The Cobb–Douglas cost function restricts the inputs to be only substitutes and the CES cost function restricts the inputs to be substitutes and/or complements. The Translog cost function relaxes these constraints and allows the degree of complementarity and substitution to be different between different sets of inputs. It also allows inferior inputs (see Hanemann, 1998).

The meaning of inputs being substitutes can be described as the following: two inputs *i* (e.g. electricity) and *j* (e.g. labour) can be categorized as substitutes if an increase in the price of input *i* leads to an increase of the demand for input *j*.

Described in the same sense, two inputs *i* (e.g. electricity) and *j* (e.g. labour) can be categorized as complements if an increase in the price of input *i* leads to a decrease of the demand for input *j*.

Typically, the demand of inputs increases when the production output increases. However, there may be cases when the demand for some inputs decreases as the production output increases. In these cases we define these inputs as inferior (second-rated) rather than normal. For example, this usually happens when an increase of production output (volumes of water) causes an increase in the demand for certain inputs/input (electricity) in exchange for other inputs/input (labour). The stated example illustrates a typical technological change when the production process gets further mechanized and the demand for labour decreases in favour of the industrial development.

$$\begin{aligned} &\ln \mathrm{TC}(w_1, w_2, y) \\ &\quad = \ln \mathrm{b}_0 + \mathrm{b}_y \ln y + \sum_{k=1}^{2} \mathrm{b}_k \ln w_k \\ &\quad + \frac{1}{2}\mathrm{d}_{yy}(\ln y)^2 + \sum_{k=1}^{2} \mathrm{d}_{ky} \ln w_k \ln y \\ &\quad + \frac{1}{2}\sum_{k=1}^{2}\sum_{i=1}^{2} \mathrm{d}_{ki} \ln w_k \ln w_k \end{aligned} \tag{9}$$

where b's and d's are the coefficients to be estimated and $\mathrm{d}_{ki} = \mathrm{d}_{ik}$.

4. Empirical application to water utilities in Sweden

This paper presents an application of the theoretical framework on a number of water and wastewater organisations in Sweden. The section specifies the estimation procedure, a structural conceptual representation that underlies the mathematical model, a description of the data samples and the resulting analysis. A model has been fitted for the total variable cost (TVC) of the production. If one wishes to fit a model of the total cost (TC) of the services, the price of capital has to be included in the model as presented in Eq. (10). Due to data limitations, the model was restricted to only capture the variable cost. However, this is not a problem for the structure analysis. Either total cost or variable cost modelling can be used to capture the cost structure of the underlying technology (Stone and Webster Consultants, Ltd., 2004). If the variable cost function is minimized with respect to the capital stock then it will yield the same economically relevant information about the underlying technology as the total cost function. But of course, the variable cost function is a representation of the variable costs in monetary terms and nothing else. It is the concepts of economies of scale, economies of customer density, economies of production output density, and economies of scope that can be assessed in the same way by using either a variable cost function or a total cost function.

$$\begin{aligned} &\mathrm{TC}\left(\text{output, prices; operational environment}\right) \\ &\quad = \mathrm{TVC}\begin{pmatrix}\text{output, prices; capital stock,} \\ \text{operational environment}\end{pmatrix} \\ &\quad + \mathrm{FC}\left(\text{price, capital stock}\right) \end{aligned} \tag{10}$$

The capital factors (= pipe length in this application) are treated as quasi-fixed inputs in the short-run, suggesting that the capital is not fully under control of the individual organisation due to external quality investment requirements (Stone and Webster Consultants, Ltd., 2004). The pipeline networks (water and wastewater) have been used as a proxy for the capital stock. The capital prices are hereby based on the network size. Other relevant proxies for the capital stock are the amount of plants, pumps, pressure stations etc. To reduce the expressions in the cost function, the analysis has been performed with only the pipe network due to limitations in available data. The simplification of the capital stock does not allow for accurate estimation of economies of scale, economies of production output density and economies of customer density in the long-run. The long-run version of the measurements requires a more accurate representation of the capital stock. Earlier relevant studies have also used a proxy for the capital stock (see for example, Garcia and Thomas, 2001) due to data limitation. Antonioli and Filippini (2001) used the number of water wells as a simplified representation of the capital stock. However, the non-identifiable inputs are not completely ignored. The inputs are enclosed in a joint *constant* (see parameter estimates). Furthermore, these non-identifiable inputs can be separated from the constant and can be incorporated as operational variables when more information will be available. The cost structure can thus be interpreted accurately although the measures are valuable only in the short-run.

In total cost modelling, the capital price has to be included in the cost function together with the price of labour, material and electricity. The capital price for the water and wastewater utility is usually measured as the cost of capital, comprising the interest rate on long-term debts and the depreciation rate (Kim, 1995). However, there are often variations in construction costs between the utilities together with different depreciation principles between communities as indicated in Section2.

According to Tagesson (2001), several differences can be observed between the Swedish communities and their capital costs due to topography, technology, large-scale production and supply from other communities.

Additionally communities use different principles of calculating capital costs, which complicates the modelling procedure. The capital price is not only a function of technology and operating environment but also a function of the depreciation principle. Tagesson (2001) states that the different principles may lead to different prices of the water service among different communities, during different time periods due to high life expectancy of water facilities.

The structure of the total variable costs of production, distribution, collection and treatment has been modelled for a number of water and sewage organisations in Sweden by using an econometric methodology and terminology. The variable cost function has been approximated by using the Translog form. The created model is used for the joint service system of water and wastewater as it was not possible to distinguish between the two types of services and to model them separately. To study sub-activities individually, separate accounting information is required, i.e. separate economical, administrational, technical and environmental figures for water supply, wastewater treatment, distribution and sewerage.

A fundamental part of the analysing procedure is to understand the underlying structure of the service system. As been described earlier, there are many different dimensions of the system that can be analysed and the researcher holds the responsibility for trying to specify what he is studying. An over-viewing description of the multivariate structure of the industry is informative in the big context, but equally important in order to fully understand the system is to describe what dimensions of the system the present study is actually focusing on. This may at least avoid conceptual confusions due to the fact that researchers tend to focus on different parts of the system. It seems to be a tendency among the econometric papers not to clearly present the research perspectives and this may underestimate the complexity of the system.

Fig. 1 represents the conceptualisation of the water and wastewater system underlying the mathematical model. The model is representative for one community that produces water to consumers and collecting the wastewater from consumers. The number of connections has been included as an operational variable whereas the capacity of the system ($m^3 h^{-1}$) and the distance to the users (km) have not been included due to lack of information. The distance to the users demonstrates the size of the network.

The data used in this study was provided from SWWA and contains operational data for 200 communities, corresponding to individual water and sewerage organisations. The material provided is extensive but there are some missing values and inconsistencies. SWWA is working in order to increase the quality level of the information. Out of 200 communities, only a sample of 25 communities were selected and used with respect to the following criteria presented in Table 2.

With respect to the limited amount of information, it seemed most reasonable to keep the model simple but as realistic as possible. The selection of operational variables and model complexity is driven by the influence on model's accuracy and the requirements of the investigation.

In order to control for different urban environments, the municipalities were selected with respect to structural similarities. The 25 selected utilities operate in similar community structures, bearing upon the distribution of households, industry and public services. Utilities that operate across communities were excluded as the collected statistical information did not clarify the number of served communities by the individual utilities.

The communities used in the study are: Bollnäs, Borlänge, Essunga, Falkenberg, Gislaved, Hagfors,

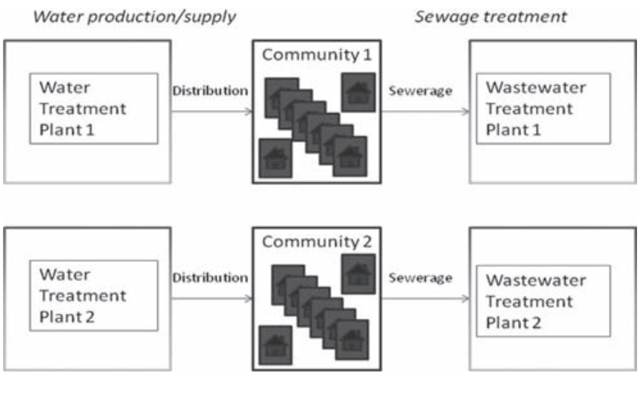

Fig. 1. Structural representation of a water supply and sewage treatment system attributed to one community.

Table 2
Selection criteria.

Included utilities	Excluded utilities
Complete cost information (O&M, electricity, labour and material).	Performing services across communities and utilities letting other communities operate all/parts of the services
Complete information about the selected operational variables (number of connections, pipe length).	Irrational operational estimates, e.g. 0% out (in) leakage
Complete information about the volume of produced water and treated wastewater	Unreasonable input prices, i.e. extremely high or low prices
Similar urban customer structure (50–80% domestic, 10–30% industrial, and 1–10% public)	

Table 3
Sample statistics, 25 observations (Annual values, year 2005).

Variable	Notation	Unit	Mean	Std. Deviation	Minimum	Maximum
Total variable cost	TVC	SEK	28446856.72	23045851.8	3946000	109213000
Production	y1	m3	3257550.32	4240649.17	244233	18351000
Sewage	y2	m3	4428141.92	4642821.84	396980	19150000
Price1: Labour and material	w1	SEK/m3	3.99	1.37	2.01	7.78
Price2: Electricity	w2	SEK/kWh	0.75	0.11	0.44	1.00
Total network length	Length	km	567.57	355.78	96	1482
Connections	Connections	–	68933.24	82476	5145	340200
Cost share1: Labour and material	S1	–	0.87	0.03	0.80	0.96
Cost share2: Electricity	S2	–	0.13	0.03	0.04	0.20

Hallstahammar, Halmstad, Herrljunga, Hjo, Härnösand, Kristinehamn, Lycksele, Mark, Mora, Norrköping, Nybro, Olofström, Ronneby, Tierp, Tingsryd, Ulricehamn, Uppsala, Vetlanda and Ängelholm.

Since the intention is to capture how the cost structure gets affected by the size of the system there was no size grouping performed. This would eliminate the size effect, which is one of the objectives of this study. Table 3 presents the overall descriptive statistics for the water and sewage organisations used in this study.

- The systems range from very small systems producing about 700 m^3 of water per day and treating about 1,100 m^3 of wastewater per day to systems producing about 50,000 m^3 water per day and treating about 52,000 m^3 of wastewater per day. The numbers in Table 3 are annual values for the year 2005, which was the only accessible year with relevant data. The large variation between minimum and maximum values reflects the different sizes between the systems, but it also indicates that there may be organizational differences. This can be observed by looking at the different prices of labour and material and electricity. Price 1 (w_1) is a "combined" unit price for labour and material and can be seen as a function of produced water and treated wastewater in cubic metres. A regularly used unit price for labour is the price per total hours worked, usually obtained by dividing total wage expenses by total hours worked. A unit price for material is recognized as difficult to establish, due to lack of homogeneity in this input. A common way to handle this is to construct a price index for input materials (see for example, Garcia and Thomas, 2001). This approach has been followed since it was not possible to separate the labour price from the material price in a satisfactory way. Both labour and materials are thus influenced by the water production and sewage variables. The labour and material price is therefore said to be endogenous (explained within the model).

4.1. Cost data

The total (annual) variable cost is the total sum of annual electricity and other annual operational costs for plants, distribution networks, pressure stations, reservoirs, storm water networks and pumps. Other annual operational costs are defined by the SWWA as the costs of labour and material (plus cost of external services)

4.2. Cost share data

The cost shares are calculated as the cost of each individual share-input divided by the total variable cost.

$$\text{Cost share1} = \frac{\text{Cost of labour and material}}{\text{Total variable cost}} \quad (11)$$

$$\text{Cost share 2} = \frac{\text{Cost of electricity}}{\text{Total variable cost}} \quad (12)$$

4.3. Price data

The price of labour and material is obtained by dividing total annual operational costs with the volume of water produced and wastewater treated during the year. The price of energy is determined by dividing total annual electricity costs by the total use of kilo waat.

4.4. Output data

The output data corresponds to the annual volume of water produced and wastewater treated. Domestic, industrial and public users constitute the main users of water and sewage.

4.5. Capital stock data

The capital stock data is represented by the length of the distribution network and length of the sewerage in kilometres. This is a rather limited representation of the capital stock.

4.6. Technical/operational data

The technical data corresponds to the amount of total connections to the water distribution network and the sewerage.

The following expression follows a Translog approximation form and represents a cost structure for the utilities chosen in this study:

$$\begin{aligned}\ln \text{TVC} = {} & \text{Constant} + a_1 \ln w_1 + a_2 \ln w_2 + b_1 \ln y_1 \\ & + b_2 \ln y_2 + c \ln \text{Length} + d \ln \text{Connections} \\ & + 0.5 a_{11} \ln w_1 \ln w_1 + a_{12} \ln w_1 \ln w_2 + 0.5 a_{22} \ln w_2 \ln w_2 \\ & + 0.5 b_{11} \ln y_1 \ln y_1 + b_{12} \ln y_1 \ln y_2 + 0.5 b_{22} \ln y_2 \ln y_2 \\ & + 0.5 cc \ln \text{Length} \ln \text{Length} + cd \ln \text{Length} \ln \text{Connections} \\ & + 0.5 dd \ln \text{Connection} \ln \text{Connections} + e_{11} \ln w_1 \ln y_1 \\ & + e_{12} \ln w_1 \ln y_2 + e_{21} \ln w_2 \ln y_1 + e_{22} \ln w_2 \ln y_2 \\ & + f_{1c} \ln w_1 \ln \text{Length} + f_{2c} \ln w_2 \ln \text{Length} \\ & + g_{1d} \ln w_1 \ln \text{Connections} + g_{2d} \ln w_2 \ln \text{Connections} \\ & + h_{1c} \ln y_1 \ln \text{Length} + h_{1d} \ln y_1 \ln \text{Connections} \\ & + h_{2c} \ln y_2 \ln \text{Length} + h_{2d} \ln y_2 \ln \text{Connections}\end{aligned} \quad (13)$$

where w_1 and w_2 are the prices for labour and material and electricity, respectively. y_1 and y_2 are the produced water and treated wastewater, respectively. The Length and Connections variables are the included operational variables in the model. The Constant is one of the parameter estimates and it encloses other omitted variables, which for all the reasons could not be caught in separate variables. The explicit parameter estimates are a_1, a_2, b_1, b_2, c, d, a_{11}, a_{12}, a_{22}, b_{11}, b_{12}, b_{22}, cc, cd, dd, e_{11}, e_{12}, e_{21}, e_{22}, f_{1c}, f_{2c}, g_{1d}, g_{2d}, h_{1c}, h_{1d}, h_{2c}, h_{2d}.

The above expression, together with the so-called *cost share equations* S_1 and S_2 forms a multivariate regression system. The cost shares are the first derivative of ln(TVC) with respect to the individual prices w_1 and w_2. Thus, we get two Cost Share equations and the system of equations to be estimated is

$$\begin{aligned}& \ln(\text{TVC}_i) = \ln \text{TVC}(y_i, w_i, CS_i, Z_i) + \text{e}_{\text{TCV}_i}, \\ & \quad \text{where } i = 1, \ldots, 25 \\ & S_{j,i} = S_{j,i}(y_i, w_i, CS_i, Z_i) + \text{e}_{\text{Share}_{j,i}}, \\ & \quad \text{where } j = 1, 2 \text{ and } i = 1, \ldots, 25\end{aligned}$$

$\varepsilon_{\text{TVC}i}$ and $\varepsilon_{\text{Share}j,i}$ are, respectively, the residuals associated with the cost equation *i* and the cost share equation *j* for utility *i*.

The system of equations has been estimated by ordinary least squares (OLS) in Matlab. The numerical values of the parameter estimates are presented in Table 4. In order to estimate the regression system above, all the variables have been normalized by their sample means. As the Translog cost function requires a reference point (Garcia and Thomas, 2001), a first-order parameters are most accurately representative for the sample mean of the total selection of 25 utilities. For example, that is to say that if the price for electricity (w_2) increases by 1%, the total variable cost will increase by a_1% for the "average" utility (i.e. an utility with mean[TVC], mean[y_1], mean[y_2], mean[w_1], mean[w_2], etc.). In addition, it can be confirmed that the mean of the estimated ln(TVC) given by Eq. (13) equals the mean of actual ln(TVC). Fig. 2 and Table 5 illustrate the model's performance.

There are certain restrictions on the model: Homogeneous of degree one in factor prices, concave in factor prices and symmetry in certain parameters ($a_{12} = a_{21}$, $b_{12} = b_{21}$). The cost shares are not allowed to be negative. The homogeneity in input prices is fulfilled when the following parameter restrictions hold:

$$\begin{aligned}& a_1 + a_2 = 1 \\ & a_{11} + a_{21} = a_{12} + a_{22} = 0 \\ & e_{11} + e_{21} = e_{12} + e_{22} = 0 \\ & f_{1c} + f_{2c} = g_{1d} + g_{2d} = 0\end{aligned}$$

Table 4
Parameter estimates.

Parameter	Corresponding variable	Estimates OLS	(White) Std. Error
Constant	Constant	17.3584	0.0132
a_1	$\ln w_1$	0.8848	0.0048
a_2	$\ln w_2$	0.1156	0.0049
b_1	$\ln y_1$	0.5116	0.0976
b_2	$\ln y_2$	0.4240	0.1013
c	ln Length	(−0.0099)	0.0504
d	ln Connections	0.0086	0.0691
a_{11}	$\ln w_1 * \ln w_1$	0.1087	0.0130
$2*a_{12} = 2*a_{21}$	$\ln w_1 * \ln w_2$	(−0.1016)	0.0121
a_{22}	$\ln w_2 * \ln w_2$	0.0900	0.0259
b_{11}	$\ln y_1 * \ln y_1$	0.0727	0.8252
$2*b_{12} = 2*b_{21}$	$\ln y_1 * \ln y_2$	(−0,0744)	0.4158
b_{22}	$\ln y_2 * \ln y_2$	0.6191	0.3223
cc	ln Length*ln Length	0.0789	0.1904
cd	ln Length* ln Connections	0.1360	0.2494
dd	ln Connections* ln Connections	(−0.1984)	0.0840
e_{11}	$\ln w_1 * \ln y_1$	0.0423	0.0177
e_{12}	$\ln w_1 * \ln y_2$	(−0.0010)	0.0165
e_{21}	$\ln w_2 * \ln y_1$	(−0.0392)	0.0182
e_{22}	$\ln w_2 * \ln y_2$	0.0008	0.0175
f_1c	$\ln w_1$*ln Length	(−0.0297)	0.0136
f_2c	$\ln w_2$*ln Length	0.0276	0.0138
g_1d	$\ln w_1$*ln Connectons	(−0.0026)	0.0080
g_2d	$\ln w_2$*ln Connections	0.0019	0.0082
h_1c	$\ln y_1$*ln Length	(−0.5378)	0.3635
h_1d	$\ln y_1$*ln Connections	0.4901	0.4864
h_2c	$\ln y_2$*ln Length	0.3225	0,3565
h_2d	$\ln y_2$*lnConnections	(−0.6311)	0.5951

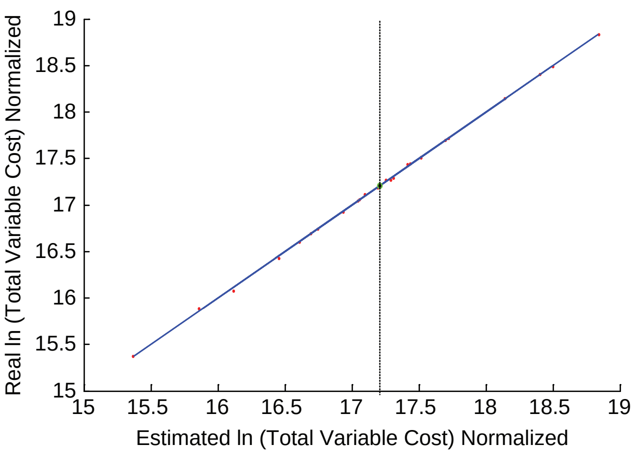

Fig. 2. Estimated ln(TVC) and actual ln(TVC).

Table 5
Cost equations performance.

Model	R^2
Cost equation	0.998
Cost share1 (Labour and material)	0.689
Cost share2 (Electricity)	0.690

After the model structure definition and parameters estimation the resulting system has been analysed by examining the critical factors and efficiency for the Swedish sample of utilities. Subsequently the mathematical measurements of Economies of production output density, customer density and scope are investigated. The meaning of Economies of scale is presented on a theoretical stage. The economies are first evaluated at the sample mean of variables, i.e. the final estimates capture the state of an "average" utility. Second, the economies are evaluated for "small" utilities [Total production: 6.4×10^5–5.0×10^6 m^3] and "large" utilities [Total production: 5.1×10^6–3.8×10^7 m^3] in the sample (Table 6).

Using the Translog approximation presented in Eq. (13), Economies of production output density in the short-run for the joint production of water and wastewater can be estimated.

$$
\begin{aligned}
&\left(\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_1} + \frac{\partial \ln \mathrm{TVC}}{\partial \ln y_2}\right)^{-1} \\
&= (b_1 + b_{11} \ln y_1^* + b_{12} \ln y_2^* + e_{11} \ln w_1^* + e_{21} \ln w_2^* \\
&+ h_{1c} \ln \mathrm{Length}^* + h_{1d} \ln \mathrm{Connections}^* + b_2 \\
&+ b_{22} \ln y_2^* + b_{12} \ln y_1^* + e_{12} \ln w_1^* + e_{22} \ln w_2^* \\
&+ h_{2c} \ln \mathrm{Length}^* + h_{2d} \ln \mathrm{Connections}^*)^{-1} \\
&= (0.5116 + 0.0727 \ln y_1^* - 0.5 \ln y_2^* + 0.0423 \ln w_1^* \\
&- 0.0392 \ln w_2^* - 0.5378 \ln \mathrm{Length}^* \\
&+ 0.4901 \ln \mathrm{Connections}^* + 0.4240 + 0.6191 \ln y_2^* \\
&- 0.5 \ln y_1^* - 0.0010 \ln w_1^* + 0.0008 \ln w_2^* \\
&+ 0.3225 \ln \mathrm{Length}^* - 0.6311 \ln \mathrm{Connections}^*)^{-1} \\
&= (0.9616 + 0.0355 \ln y_1^* + 0.5819 \ln y_2^* + 0.0413 \ln w_1^* \\
&- 0.0384 \ln w_2^* - 0.2153 \ln \mathrm{Length}^* \\
&- 0.1410 \ln \mathrm{Connections}^*)^{-1} \\
&= \{\text{for the "average" utility}\} \\
&= (0.5116 + 0.4240)^{-1} \\
&= 1.06
\end{aligned}
\tag{14}
$$

Notation in the formula (*): Normalized variables.

Table 6
Definition of efficiency measures.

Measure	Decreasing return to size	Constant return to size	Increasing return to size
Economies of production output density[a]	<1	1	>1
Economies of customer density[a]	<1	1	>1
Economies of scale[a]	<1	1	>1
Measure	Joint production	Separate production	
Economies of scope[b]	<0	>0	

Sources: [a]Garcia and Thomas (2001), [b]Hajargasht et al. (2006).

Table 7
Estimated economies of production output density and customer density for different utility sizes.

Measure	"Small" utilities in the sample	The "average" utility	"Large" utilities in the sample
Economies of production output density	= 1.34 Marked increasing return to size	= 1.06 Increasing return to size (roughly constant return to size)	= 0.86 Decreasing return to size
Economies of customer density	= 1.04 Increasing return to size (roughly constant return to size)	= 1.03 Increasing return to size (roughly constant return to size)	= 0.87 Decreasing return to size

The expression shows us that the economies of production output density for the Swedish utilities "overall" are dependent mostly on the treatment of wastewater, the capital stock (represented by *Length*) and the amount of connections. Wastewater is a critical factor among the utilities, especially for utilities with large production of treated wastewater. This can be attributed to expensive treatment procedures or/and increased in-leakage (over flow). In-leakage is water that enters into the sewage network although it does not belong in the system, for example rainwater, groundwater or surface water that forces themselves into wells and pipes. The amount of in-leakage water in the system can vary between 0 and several hundred percent of the normal water flow (Weglert, 2005) and is related to storm events.

On the other hand, the effect of wastewater for the average firm is not that critical as it is for larger production. A force of direction, if the volume of water supplied to customers increases by 1% (all other things unchanged) then the total variable cost increases by approximately 0.51% for the average firm. If the volume of wastewater increases by 1% (all other things unchanged) then the total variable cost increases by approximately 0.42%. Conclusively, water and wastewater are about equally affecting the total variable cost for the average utility. As it can be seen in Eq. (14) the price of electricity has a higher effect (it is a sensitivity factor) on the total variable cost when the amount of wastewater increases than when the amount of water increases. On the other hand, the price of labour and material has a higher effect on the total variable cost when the amount of water increases when compared to an increase in wastewater.

The estimated economies of production output density are 1.06 for the average utility. This leads us to conclude that the average utility exhibits Economies of production output density (returns to size are increasing, because economies of production output density > 1). It would be profitable to produce more units of goods with the existing network and the amount of existing customers (i.e. to have an increasing demand from the existing users to produce water and to clean wastewater). On the contrary, it would not be profitable for the large utilities to produce more units of goods with their existing network and their amount of existing customers (Table 7).

Following the same approach, economies of customer density in the short run for the joint production of water and wastewater can be estimated by the following equation:

$$\left(\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_1}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_2}+\frac{\partial \ln \mathrm{TVC}}{\partial \mathrm{Connections}}\right)^{-1} = \left(0.5116+0.4240+0.0086\right)^{-1} = 1.03 \quad (15)$$

One percent increase of the number of connections (while keeping all other parameters/characteristics unchanged) results in approximately a 0.0086% increase of the total variable cost for the average utility. A proportional increase of 1% respectively of the volume of water, the volume of wastewater and the amount of connections brings about an 0.97% increase of the total variable cost for the average utility.

As the estimated economies of customer density are 1.03 for the average utility, the average utility exhibits economies of customer density (returns to size are increasing, because economies of customer density > 1). It would be profitable for the average utility and for the small utilities to serve more customers (thus to also produce more units of goods) in their existing network. On the contrary, it would not be profitable for the large utilities to serve more customers with their existing network. The larger utilities does not benefit from customer growth when having their existing network.

A theoretical measure of Economies of scale in the short run and in the long run can be estimated using Eqs. (16) and (17), respectively:

$$\left(\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_1}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_2}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Connections}}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Network\,size}}\right)^{-1} \quad (16)$$

$$\frac{1-\dfrac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Capital\,stock}}}{\dfrac{\partial \ln \mathrm{TVC}}{\partial \ln y_1}+\dfrac{\partial \ln \mathrm{TVC}}{\partial \ln y_2}+\dfrac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Connections}}+\dfrac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Network\,size}}} \quad (17)$$

The Network size as presented in the previous formulas is a geographical representation/measure of the service region. The size of a network can be measured in e.g.

a. km (the length of the total pipe network)
b. km^2 (the area of the service region)
c. communities (the amount of communities that form a service region)

The representation of the network size in the formulas depends on enlargement of a utility. By the definition of economies of scale, the density of customers has to remain unchanged once volume of the produced water has changed. If the network size is represented only by one parameter; option (a) – the length of the total pipe network – then the proportionally varying variables are the supplied water, the treated wastewater, the amount of customers and the length of the total pipe network. Thus, the resulting measure of customer density (Customers/km) remains unchanged. Since there is no representation for the area, the measure of customers per area (Customers/km^2) may have increased, remained the same or decreased. In the same manner, since there is no representation for the amount of communities, the measurement of customers per community (Customers/community) may have increased, remained the same or decreased. In order to control for an area variation (e.g. an enlargement), one more expression should be included in the equation. In order to control for community consolidations, one more expression should be included in the equation. All of the possible size variations should preferably be included in the mathematical formula in order for the desired customer density to remain unchanged once the production has varied in size e.g. Customers/(km and km^2 and community). Here is a general formula for the short-run case with more than one network size representation:

$$\left(\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_1}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln y_2}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln \mathrm{Connections}}+\frac{\partial \ln \mathrm{TVC}}{\partial \ln(a)}(+)\frac{\partial \ln \mathrm{TVC}}{\partial \ln(b)}(+)\frac{\partial \ln \mathrm{TVC}}{\partial \ln(c)}(+)\cdots\right)^{-1} \quad (18)$$

There was no information about the area (e.g. in km^2) of the service regions or the amount of served communities, which meant that it was not possible to estimate on the proper measurement of Economies of scale.

There are economies of scope between water and wastewater in the Swedish industry, i.e. it appears to be cost advantages with the joint production of water and wastewater.

$$\text{Economies of scope}\left(\text{water and wastewater}\right) = \frac{\partial^2 \log(\mathrm{TVC})}{\partial \log Y_1 \partial \log Y_2} = b_{12} = \frac{-0.0744}{2} < 0 \quad (19)$$

An indicative example of customer analysis, in comparison to production analysis is given to complete the analysis. The parameter estimates are based on estimation procedures like the previous ones. The estimates in this subdivision should rely on an approximation procedure due to missing values. Economies of production output density in the short run for the joint production of water and wastewater to domestic users and industry users are estimated as following:

$$\left(\frac{\partial \ln \text{TVC}}{\partial \ln y_{\text{domestic}}} + \frac{\partial \ln \text{TVC}}{\partial \ln y_{\text{industry}}}\right)^{-1} = (0.5428 + 0.4225)^{-1} = 1.04 \quad (20)$$

Public users, as they are a small part of the total production, have been excluded whereas the measurement of economies of production output density with the customer perspective gives almost the same result as the analysis with the product perspective. The result of 1.04 is a little less than the previous 1.06, which may be the result of not including the public users. It can be concluded that domestic users have a large effect on the total variable cost of production. A 1% increase of the total water and wastewater demand from domestic users (all other things unchanged) brings about a 0.54% increase of the total variable cost whereas a 1% increase of the total water and wastewater demand from industry users (all other thing unchanged) brings about a 0.42% increase of the total variable cost.

$$\text{Economies of scope (domestic and industry)} = \frac{\partial^2 \log(\text{TVC})}{\partial \log Y_{\text{Dometic}} \partial \log Y_{\text{Industry}}} = \frac{0.6725}{2} > 0 \quad (21)$$

The estimate of economies of scope is greater than 0 which indicates that it is not profitable for the average utility to serve both domestic and industry users. It seems to be more profitable to specialize in different production units. This contradicts a study made by Kim (1995) that found cost advantages of operating with a combination of residential and residential outputs for a cross-section of 60 utilities for the year 1973 in the United States. Excluding the possibility of estimation errors, the individual industry analysis can be seen as case-specific, depending on the underlying production technology and environment. The analysis can be spit up into different product, customer or function groups.

5. General discussion and conclusions

An economic/mathematical model for the water and wastewater industry has been constructed by using a multivariate regression approach. The selection of a mathematical formula (including explanatory variables) in order to apply on the statistical data is based on the desired venture. A second (alternative) approach is the stochastic frontier analysis. While the regression method generates an expression of the average cost, the stochastic frontier method determines how close each utility is to the expenditure achieved by the best of the industry. The second approach is often used for the purpose of benchmarking (Finn, 2006).

Each estimated parameter in the mathematical formula describes the relationship between the total (variable) cost and the corresponding system input. The parameters represent a cost structure for a few Swedish utilities in the water industry.

In order to properly build a mathematical model of a single system (or total industry) a broad understanding on the underlying production technology is required. A critical step is to clarify which structural-conceptual representation that is going to be described by the mathematical model. This step can be approached from a dimensional perspective.

The Translog cost function is better interpreted as a "cost structure function" for the existing industry rather than a "cost estimation function" for new constructions. The Translog cost function has been normalized in order to be easily interpreted for an average utility. The efficiency measures have been derived from the variable cost formula and have been calculated for different sizes of the utilities ("small", average and "large"). The coefficient of the capital stock has a negative sign, which follows the cost theory (Filippini et al., 2007).

The estimations need to be refined with more sophisticated econometrical methods as the parameter restrictions for w_1 and w_2 are not perfectly fulfilled (the parameters $a_1 + a_2$ does not summarize perfectly to 1). Moreover, the data used for this study is cross-sectional data (i.e. data-sets that do not reflect difference in time). More interesting would be the use of panel-data (i.e. data-sets that reflects changes in time).

The efficiency measures can be estimated for every utility in the study, although the measures are most accurately interpreted for the average utility. The average approach is a common way of representing the conditions of an industry. However, the average utility is a fictive utility based on actual values of the existing industry and cannot be identified independently. This study points out the need for improved quality methods of collecting information and presenting statistics about the water industry.

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