J Prod Anal (2016) 45:215–228
DOI 10.1007/s11123-016-0468-0

Economies of scale in Peru's water and sanitation sector

Augusto C. Mercadier[1] · Walter A. Cont[2] · Gustavo Ferro[3]

Abstract This paper quantifies economies of scale in Peru's water and sanitation (W&S) sector based on a five-year panel (2006–2010) that examines 39 water services providers. Our findings highlight the lack of economies of scale in the Peruvian W&S sector as a whole. Cost savings are possible through water volume increases (*Economies of Production Density*) and a higher provision density (*Economies of Customer Density*), but not via an increase in the number of served municipalities (overall *Economies of Scale*). Some agglomerations are possible, yielding cost reductions of up to 9 %.

Keywords Economies of scale · Water and sanitation · Peru · Econometrics

JEL Classification D61 · L5 · L95

1 Introduction

Water and sanitation (W&S) is mostly provided by local governments throughout the world. In Latin America, local authorities have faced serious difficulties in achieving good performance and productivity, which has led to studies on ways to improve W&S services management and sustainability (see Revollo and Londoño 2010; Corton 2011). Relevant alternatives include exploiting economies of scale through mergers.

The underperformance of the W&S sector has been a recent policy issue in Peru. In 2013 the national government enacted the Sanitation Services Modernization Law to promote regional integration of Sanitation Services Providers (henceforth "SSPs") in order to take advantage of potential economies of scale, reduce production costs and achieve a more technical and efficient management among other things. Economies of scale were expected to be achieved by extending the coverage of SSPs from main urban areas to the whole territory.

This paper analyzes the presence of economies of scale and the advantages of possible SSP mergers (in terms of cost-efficiency). To address this issue we first encompass different cases of service expansion into the definition of economies of scale. Second, we quantify economies of scale in Peru's urban W&S sanitation sector. Third, we determine the margin of average costs reduction that can be achieved through mergers and discuss the conditions for such savings to take place.

We conclude that, although the Peruvian W&S sector does not present economies of scale as a whole, cost savings could be achieved by increasing water production (measured in volumes) and by increasing the density of customers (measured in number of connections) within a single provision area but not by extending the service area. With these

---

✉ Augusto C. Mercadier
amercadier@econo.unlp.edu.ar

Walter A. Cont
walter@fiel.org.ar

Gustavo Ferro
gferro05@yahoo.com.ar; gaf97@ucema.edu.ar

[1] ERAS and Universidad Nacional de La Plata, Callao 982, 1023 Buenos Aires, Argentina

[2] FIEL and Universidad Nacional de La Plata, Córdoba 637, 1054 Buenos Aires, Argentina

[3] Universidad del CEMA (UCEMA) and CONICET, Córdoba 374, 1054 Buenos Aires, Argentina

results, we identify individual SSPs exhibiting economies of scale and assess potential cost reductions of up to 9 % when consolidating with other close-by providers.

This paper is organized as follows: Sect. 2 describes the W&S sector in Peru. Section 3 introduces the main concepts concerning economies of scale. Section 4 reviews the empirical literature on economies of scale in the W&S sector. Section 5 presents the methodology, model and data to estimate the cost function of W&S in Peru. Section 6 shows the results, estimates economies of scale and analyzes policy issues. Section 7 summarizes our main findings and conclusions.

2 The water and sanitation sector and economies of scale

2.1 Water and sanitation sector production process

The main objective of water services is to produce water which meets the minimum quality standards from resources (groundwater or surface water) that may necessitate preliminary treatments to make water safe and potable, and to distribute such water to supply final users throughout distribution networks. Therefore, production can be decomposed into two main functions or stages: production or resource extraction (from groundwater or surface water) and preliminary treatment (disinfection, iron removal, filtering, softening, etc.). Transmission and Distribution, on the other hand, involve four activities: transportation of water between production facilities through transmission pipelines (transmission); storage of water in facilities such as water tanks and water towers; pressurization of water in pipelines, either by a gravity main system or with the help of pumping stations; and distribution of water to final customers through distribution networks and customer service lines.

The cycle is completed with the collection and transportation of sewage from customers to disposal bodies (the "sanitation" stage). In some cases sewage is treated in treatment plants before its final disposal in order to minimize environmental harm.

Additionally, for both water and sanitation, providers maintain and repair networks, make quality controls, attend to customer claims and deal with regulators, in-house or through outsourcing. Administrative and commercial tasks, billing, accountancy, finance and human resources are typically integrated in the W&S sector, although certain exceptions exist.

2.2 The organization of W&S in Peru

Peru is politically divided into 24 departments, and one constitutional province. The departments are divided into 196 provincial municipalities, which are divided into 1838 districts. The Constitution authorizes municipalities to "Organize, regulate and manage local public utilities under their responsibility" and to "…develop and regulate activities and/or W&S services […]". The General Sanitation Services Law establishes that provincial municipalities are in charge of W&S provision; hence they are allowed to define exploitation rights to providers, according to the law and regulations. Likewise, the Organic Municipalities Act establishes that provincial municipalities and districts are jointly responsible for the management and regulation of W&S concessions.

More than 1500 districts (20 % of the urban population) are served by local Sanitation Services Boards. The remaining 300 districts (80 % of the urban population) are served by 50 SSPs. These providers supply a population of over 17 million, 15 million of which receive water service and 13 million receive sewage services. SSPs cover at least one provincial municipality and are regulated by the national W&S regulator ("*Superintendencia Nacional de Servicios de Saneamiento*", SUNASS). Only one of the 50 SSPs is a national provider (SEDAPAL, serving Lima, the nation's capital), another SSP is a private concession provider, and 48 are public municipal enterprises.

In June 2013 the National Government enacted the Sanitation Services Modernization Law 30045 (the "W&S Modernization Law" henceforth).[1] This Law allowed the Ministry of Housing, Building and Sanitation (the "Ministry") to create a Technical Agency to Manage Sanitation Services ("*Organismo Técnico de Administración de Servicios de Saneamiento*", OTASS) to promote consolidation and mergers between SSPs in order to take advantage of economies of scale, reduce production costs and achieve a more technical and efficient management, among other things. In addition, the Law determined that the Ministry should define mechanisms to promote consolidation and merger of SSPs. In November 2013, Presidential Decree 015-2013 defined the integration of sanitation services as a gradual process in which different SSPs within the same geographical area were to be unified at a regional level, in order to optimize provision of W&S.[2] According to the Decree, economies of scale were expected to be achieved by extending the scope of SSPs from main urban areas to the whole territory. Hence, the implementation of such goal included two possibilities: (1) the expansion of service provision to areas currently not covered by SSPs; and (2) the merger of local SSPs into supra-provincial or regional SSPs. In this sense, it is expected that OTASS will foster regional integration by (1) allowing mergers of SSPs, (2)

---

[1] See the link to access the full text.

[2] See the link http://faolex.fao.org/docs/pdf/per129262.pdf to access the full text.

extending SSPs coverage to areas served by local Sanitation Services Boards, (3) extending SSPs coverage to areas served by rural providers. Regarding the proposals for SSPs integration, the Decree established that OTASS should have prepared a proposal for W&S consolidation and published it on its institutional web site by August 2014. As of October 2015, the proposal has not been published yet.

3 Cost minimization and economies of scale in W&S

3.1 Cost minimization problem

W&S providers produce an output vector $y = (y_a, y_s)' \geq 0$, where y_a is water billed and y_s is sewage collected. Ideally, we should consider both services independently and assess the existence of scope economies between the two. However, two main reasons prevent us from doing so. From a policy point of view, horizontal fragmentation is not an option since the General Sanitation Services Law establishes that the SSPs are responsible for the integrated system of W&S (that is, production and distribution of drinking water, and treatment and disposal of wastewater). From an empirical point of view, sewage services are billed as part of the water bill, which renders disaggregation of monetary variables at service level difficult and unreliable.[3] Alternatively, we could deem sewage treatment as a separate product. However, since only half of Peru's SSPs effectively treat sewage, we consider it a quality variable. Therefore, this paper will refer to the output as a compound water-and-sanitation service.[4]

The inputs used to produce W&S output are labor (x_l), services outsourced to third parties (x_t), capital (x_k) and other expenses (x_o). The latter is a residual category that covers many aspects (electricity, chemical products, fuel, and others) that are difficult to single out. We assume that the technology is the same for all productive units.

Cost levels could be affected differently depending on environmental conditions or quality of service requirements.[5] Indeed, Feigenbaum and Teeples (1983) and Fabbri and Fraquelli (2000) assess that a distinctive characteristic of the W&S industry is that companies use inputs to transform the location and quality of water (i.e., to make it available and potable) to customers, rather than producing output out of inputs. The same applies to sanitation, as wastewater has to be collected from customer's location and disposed of according to environmental standards and depending on disposal capacity and location.

The production function is defined as $f(y, x; z) = 0$, where $x = (x_l, x_t, x_o, x_k)$ is the input vector, z is the environmental vector and y is the output vector. Assuming price-taking behavior and input-price vector $w \equiv (w_l, w_t, w_o, w_k)' \gg 0$, SSPs choose input–output to minimize long-run costs

$$\min_{x \geq 0} \sum_{i=l,t,o,k} w_i x_i \quad \text{subject to} \quad f(y, x; z) = 0 \tag{1}$$

Let $C(y, w; z)$ be the indirect cost function. This function satisfies the properties of being non-negative, non-decreasing in $y \geq 0$ and in $w \gg 0$, homogeneous of degree one in prices, concave and continuous in w (Panzar 1989).

The adoption of a long-run cost minimization strategy implies that SSP managers solve a program choosing all inputs. In practice, however, capital stock is a quasi-fixed input and the cost of capital is hard to determine. In order to tackle this problem, some authors estimated a short-run cost function (which should satisfy the same properties as the long-run cost function plus an extra condition of being non-decreasing in capital). But in this case, García and Thomas (2001) showed that the long-run total cost function can be recovered from the variable cost function only if the latter is minimized with respect to capital stock, and this means that the derivative of variable cost with respect to capital is equal to the negative of the cost of capital. Panzar (1989) highlights this paradox that variable costs are used to avoid defining the cost of capital but then this cost is needed to establish the long-run relationship. Some empirical work privileged the short-run approach and recovered the long-run relationship through variable costs at the expense of assuming that the capital stock was optimal (see Table 1 in Sect. 4). Authors who tried to estimate this effect properly found a positive—rather than negative—relationship between variable costs and capital (see, for example, Bottasso and Conti 2009). Given the complexities and problems of recovering long-run relationships from short-run estimations and the fact that the cost of capital is available in the case of Peru, we follow the long-run approach.

3.2 Economies of scale in W&S

The cost minimization problem in Sect. 3.1 leads to an indirect cost function $C(y, w; z)$. Since increases in production (water volume) could be attributed to higher consumption by existing customers, new customers, and/or the extension of coverage area, the incremental cost (per unit

---

[3] In an early version of this paper we tried to analyze economies of scope between water and sanitation outputs but we came across issues of co-linearity when we included both services. Corton (2011) also finds this problem. One possible explanation is that in many cases cubic meters of wastewater collected are estimated as a fraction of the water consumed.

[4] On this issue see Bottasso et al. (2011).

[5] We consider these as environmental variables or control variables, interchangeably.

Table 1 Economies of scale in W&S—empirical studies

Author and date	Production density			Customer density			Economies of scale		
	Variable costs	Long-run variable costs	Total costs	Variable costs	Long-run variable costs	Total costs	Variable costs	Long-run variable costs	Total costs
Antonioli and Filippini (2001)		1.46			1.16			0.95	
Ashton (1999)		0.96							
Baranzini and Faust (2009)	1.56	1.03	1.22						
Bhattacharyya et al. (1994)	1.17								
Bhattacharyya et al. (1995)	1.27								
Bottasso et al. (2011)			2.50				1.23		
Bottasso and Conti (2009)		3.76			1.42			1.12	
Corton (2011)			1.58–1.81						
Destandau and García (2014)	1.73–2.05			1.16–1.30				1.00–1.08	
Fabbri and Fraquelli (2000)			1.58			0.99			
Feigenbaum and Teeples (1983)			1.16						
Filippini et al. (2008)			3.87			1.31			1.09
García et al. (2007)	1.59						1.40	1.17	
García and Thomas (2001)	1.14	1.20		1.05	0.87			1.00	
Hayes (1987)			1.17						
Hunt and Lynk (1995)			2.45						
Iimi (2008)			1.15			1.21			
Kim and Clark (1988)			0.99						
Kim and Lee (1998)			1.26			0.98			
Martins (2008)			1.49						
Mizutani and Urakami (2001)			1.10						0.92
Revollo and Londoño (2010)	1.69	1.31						0.95	
Saal and Parker (2000)									0.83
Saal et al. (2007)									0.86
Sauer (2005)							2.09	2.09	
SCL Econometrics (2009)									1.29
Stone & Webster (2004)	0.67	0.62	0.71						
Torres and Morrison-Paul (2006)	1.72			0.93			0.81		
Tynan (2005)			1.02–1.32						
Urakami and Parker (2011)			1.08						
Mean	1.41	1.48	1.54	1.05	1.15	1.12	1.38	1.19	1.00

Source: Authors' own compilation based on authors and surveys of the literature

of volume) does not fully register the optimum scale of a provider. The distinction between volume (y), customer density (proxied by the number of connections Cx) and provision area (measured in localities served Lc) in the cost function makes it possible to identify and measure economies of production density, customer density and scale.[6]

Economies of production density (E_{PD}) measure the percentage change in costs compared to increases in y, leaving constant Cx and Lc.[7] Economies of production density exist when the average variable costs decrease as the production increases for a given network size and

---

[6] See García and Thomas (2001), Torres and Morrison-Paul (2006), Filippini et al. (2008) and Destandau and García (2014).

[7] Torres and Morrison-Paul (2006) refer them to as "economies of volume" and Bottasso and Conti (2009) as "economies of output density".

number of users (i.e., the water delivery per user increases). In this case, $E_{PD} > 1$, where

$$E_{PD} = \left[\frac{\partial \ln C(y, w_i, z)}{\partial \ln y}\right]^{-1} \tag{2}$$

Economies of customer density (E_{CD}) measure the percentage change in costs compared to increases in y and Cx, leaving constant Lc (notice that demand per customer is constant in this case; if production were not changed then the new customers would impose an externality on the old ones because they would not be allowed to consume the same volumes of water they were consuming). There are economies of customer density if $E_{CD} > 1$, where

$$E_{CD} = \left[\frac{\partial \ln C(y, w_i, z)}{\partial \ln y} + \frac{\partial \ln C(y, w_i, z)}{\partial \ln Cx}\right]^{-1} \tag{3}$$

Economies of scale (E_S), or *size economies*, measure the percentage change in costs when y, Cx and Lc increase proportionally. There are scale economies if $E_S > 1$, where

$$E_s = \left[\frac{\partial \ln C(y, w_i, z)}{\partial \ln y} + \frac{\partial \ln C(y, w_i, z)}{\partial \ln Cx} + \frac{\partial \ln C(y, w_i, z)}{\partial \ln Lc}\right]^{-1} \tag{4}$$

Equation (3) is useful to assess cost changes of expanding service provision to customers currently not covered by, but within the same area of, the corresponding SSP (this is the first option of implementation of the W&S territorial integration mentioned in Sect. 2.2). On the other hand, Eq. (2) is relevant to assess the cost changes resulting from merging two contiguous providers or absorbing small service providers, with the consequent consolidation into supra-provincial or regional SSP (this is the second option of implementation of the territorial integration of W&S mentioned in Sect. 2.2). The definition assumes that the newly incorporated areas have the same customer density and consume the same volumes as the pre-existent ones.[8]

4 Literature review

Many papers survey economies of scale in W&S (see, for example, Abbott and Cohen 2009; Walter et al. 2009; Ferro et al. 2011; Saal et al. 2013). Table 1 highlights the quantitative results found in those papers, sorting them according to (the) three concepts of economies (production, customer, scale) and to whether they used a long-run or short-run approach.

From this review we can assess the importance that researchers have given to the definition of scale economies and the implicit difficulties that they were faced with. They produced 32 estimates of economies of production density, ten estimates of economies of customer density and 16 estimates of economies of scale.

Firstly, on average, economies of production density are a good measure of economies of scale at the production and treatment stage. Average estimates range from 1.41 (short run) to 1.54 (total costs). Additional volume delivered to existing customers within the service provision area increases costs less than proportionally.

Secondly, economies of customer density are a proxy for customer expansion. Cost estimates include distribution costs in addition to production and treatment costs, and volume changes take into account the number of customers (holding the volume of water per connection constant). Although average estimates exceed the unit value (they range from 1.05 to 1.15), an important share of papers find diseconomies (40, vs. 15 % in the case of production density).

Thirdly, economies of scale consider service expansion through a proportional increase in volume, customers and service area. Average estimates range from 1.00 to 1.38 implying economies of scale. However, some papers find diseconomies (38 %).

From these results, it can be inferred that consolidation of providers based on production density definition would be advised in most cases, but it should be assessed on a case-by-case basis if based on customer density or economies of scale definitions.

Two papers from Table 1 analyze economies of scale in Peru (Tynan 2005; Corton 2011). Tynan (2005) use a cross section of 270 W&S providers (including 41 SSPs from Peru) to examine economies from the point of view of (1) changes in served population, (2) connections, (3) output volume and (4) network length. The authors find constant returns to scale for output volume and network length, but diseconomies of scale for served population and connections. When they split the sample by size (the cutoff being a served population of 125,000 inhabitants), they observe economies of scale for small-sized firms and constant returns to scale for larger firms in the case of output volume, but they find diseconomies of scale at all sizes when it comes to number of connections.

Tynan (2005) do not make the functional form explicit, beyond assuming constant (dis)economies of scale for the whole data range. Therefore, they implicitly assume that there is no optimal size for W&S provision. Second, when analyzing the effects for output volume it is impossible to disentangle whether this output corresponds to expansion of service area or increase in consumption. Third, they do not use control variables to account for environmental and/or quality factors, which is standard in the literature—

---

[8] An extension of the provision area without increasing the number of connections accordingly would imply that the number of new customers crowds-out an equal number of old ones or that the extension goes to an area with no connection to be served.

Mizutani and Urakami 2001, Stone and Webster 2004, Saal and Parker 2000, risking bias in the results.

Corton (2011) studies the structure of W&S provision in Peru and examines economies of scale and the cost inefficiency of 43 SSPs during the 1996–2005 period (almost all of them are state-owned enterprises). The author considers SSPs as producers of two services—water and losses—and assumes that water producers allow water leaks as a way to satisfy the water demand of the poor. Hence, spilled water is the political cost of gaining municipal votes from the poorest segment(s) of the population.

There are several differences between the present paper and Corton (2011). Firstly, Corton (2011) estimates cost frontier and cost inefficiencies (as the distance of each SSP to the cost frontier following a stochastic frontier analysis). Moreover, she defines economies of scale in a way that corresponds to economies of production density according to the definitions provided above. This paper estimates the cost function through a system of equations that allows us to impose theoretical constraints on parameter values, and hence measure the three alternatives of economies of scale (production density, customer density and scale). Secondly, Corton (2011) embeds the estimation of cost economies into a political economy problem while this paper follows the economics approach on costs. She assumes that consumption by the poorest segment of the population is the sole reason for unaccounted for water, not allowing other possibilities such as pipe leaks, network obsolescence, or lack of maintenance or metering. Lastly, Corton (2011) uses a set of dummies to account for all the heterogeneity among SSPs while this paper uses dummies as well as environmental and quality control variables.

5 Empirical approach and database

5.1 The empirical problem

We use a translogarithmic (or "translog") specification to estimate the empirical model from Eq. (1), which is the standard strategy in most researches (see observations in Ferro et al. 2011). This specification is more flexible than other representations, does not impose a priori constraints on the elasticity of substitution and allows for variable economies of scale, capturing the U-shape of average costs if it exists. The Cobb-Douglas function is a special case after imposing certain constraints on its parameters. The drawback of the function is that as it is a local approximation, the results are only reliable near the point of expansion and it is undefined for values equal to zero. The function applicable to this case is as follows:

$$
\begin{aligned}
\ln C = {} & \ln \alpha + \sum\nolimits_{j=1}^{J} \beta_j \ln y_j + \sum\nolimits_{m=1}^{M} \gamma_m \ln w_m + \sum\nolimits_{l=1}^{L} f_l \ln z_l \\
& + \frac{1}{2} \sum\nolimits_{i=1}^{J} \beta_{ij} \ln y_i \ln y_j \frac{1}{2} \sum\nolimits_{i=1}^{M} \sum\nolimits_{j=1}^{M} \gamma_{ij} \ln w_i \ln w_j \\
& + \frac{1}{2} \sum\nolimits_{i=1}^{L} \sum\nolimits_{j=1}^{L} \ln z_i \ln z_j + \sum\nolimits_{j=1}^{J} \sum\nolimits_{m=1}^{M} \gamma_{jm} \ln y_j \ln w_m \\
& + \sum\nolimits_{j=1}^{J} \sum\nolimits_{l=1}^{L} f_{jl} \ln y_j \ln z_l + \sum\nolimits_{m=1}^{M} \sum\nolimits_{l=1}^{L} h_{ml} \ln w_m \ln z_l
\end{aligned}
\tag{5}
$$

where J is the number of outputs (product, customers and localities), M is the number of inputs and L is the number of environmental and quality variables.

As is known from the literature, the number of parameters to estimate is quite large, but it can be reduced by normalizing costs and input prices by the price of a certain input, in this case, third-party services, ensuring the fulfillment of the homogeneity of degree 1 in input prices. Defining $p_l = w_l/w_t$, $p_k = w_k/w_t$ and $p_o = w_o/w_t$, we can rewrite the cost function (5) as:

$$
\begin{aligned}
\ln (C/w_t) = {} & \ln \alpha + \sum\nolimits_{j=1}^{J} \beta_j \ln y_j + \sum\nolimits_{m=1}^{M-1} \gamma_m \ln p_m + \sum\nolimits_{l=1}^{L} f_l \ln z_l \\
& + \frac{1}{2} \sum\nolimits_{i=1}^{J} \sum\nolimits_{j=1}^{J} \beta_{ij} \ln y_i \ln y_j + \frac{1}{2} \sum\nolimits_{i=1}^{M-1} \sum\nolimits_{j=1}^{M-1} \gamma_{ij} \\
& \ln p_i \ln p_j + \frac{1}{2} \sum\nolimits_{i=1}^{L} \sum\nolimits_{j=1}^{L} f_{ij} \ln z_i \ln z_j \\
& + \sum\nolimits_{j=1}^{J} \sum\nolimits_{m=1}^{M-1} \gamma_{jm} \ln y_j \ln p_m + \sum\nolimits_{j=1}^{J} \sum\nolimits_{l=1}^{L} f_{jl} \ln y_j \ln z_l \\
& + \sum\nolimits_{m=1}^{M} \sum\nolimits_{l=1}^{L} h_{ml} \ln p_m \ln z_l
\end{aligned}
\tag{6}
$$

The parameters to estimate are: $\alpha, \beta_j, \gamma_m, f_l, \beta_{ij}, \gamma_{ij}, f_{ij}, \gamma_{jm}, f_{jl}$ and h_{ml}.Let S_m represent the share of input m in variable costs. Shephard's Lemma establishes that:

$$
x_m = {}^{\partial C}\!/_{\partial w_m} \rightarrow {}^{w_m x_m}\!/_{C} = {}^{\partial C}\!/_{\partial w_m} . {}^{w_m}\!/_{C} \rightarrow S_m = {}^{\partial \ln C}\!/_{\partial \ln w_m}
$$

Replacing these conditions into (6) we get:

$$
S_m = \gamma_m + \sum_{i=1}^{M} \gamma_{mi} \ln p_i + \sum_{j=1}^{J} \gamma_{ji} \ln y_j + \sum_{l=1}^{L} h_{ml} \ln z_l, \text{ with m} = l,\, o,\, k \tag{7}
$$

We estimate a system of equations composed by the total cost Eq. (6) and three share equations:

$$
\ln(C_{it}) = \ln C(y_{it}, w_{it}, Z_{it}) + u_{C,it}, \text{with i } = 1, \ldots, I \text{ and } t = 1, \ldots, T \tag{8}
$$

$$
S_{j,it} = S_j(y_{it}, w_{it}, Z_{it}) + u_{s_j,it}, \text{with; } i = 1, \ldots, I \text{ and } t = 1, \ldots, T \tag{9}
$$

where $i = 1, \ldots, I$ labels SSPs, $t = 1, \ldots, T$ corresponds to periods of time, $j = l, o, k$ identifies inputs (except the one chosen as numeraire), $u_{C,it}$ are the residuals associated with $ln(C_{it})$ and $u_{s_j,it}$ are the residuals associated with the share equations. We check *ex post* that shares are positive, verifying that the cost function is non-decreasing in the factor prices.

We allow for contemporaneous correlation of error terms across equations. The system (8)–(9) is the empirical form of Eqs. (6)–(7). We apply the iterated *Seemingly Unrelated Regression* (SUR) method.

Our model does not allow for free correlation between $u_{C,it}$ or $u_{s_j,it}$ and the regressors. In order to tackle this problem we discarded the fixed effects option and estimated a random effects model, introducing a set of dummies related to location, sewage treatment or water sources which may account for time invariant cost differentials not already captured in the model (Bottasso and Conti 2009).

Because the translog function requires a point of expansion, explanatory variables have been normalized around the sample median, the latter being the reference for local approximation. Thus, the direct effects of the variables can be interpreted as elasticities without considering the second derivatives.[9]

5.2 Database description

Our database was built from two sources. In 2006, SUNASS approved the SSP Performance Indicators' System and introduced a methodology to calculate the indicators (*Indicadores de Gestión*, or "IG").[10] Every year SUNASS produces a Technical Report on SSP Activity detailing these IG.[11] The second source comes from Tariff Studies (*Estudios Tarifarios*, or "ET") published also by SUNASS in its web page.[12]

The full sample consists on a panel of 50 SSPs over 5 years (2006–10), which collapses to 39 SSPs (and 195 observations) after removing inconsistencies and missing values. Table 2 summarizes the descriptive statistics of the variables and the column "Source" specifies the data source.

Total cost (C) is calculated as the sum of variable costs (excluding depreciations) and capital cost (measured as opportunity costs and depreciation rate of fixed assets multiplied by the value of fixed assets). Output (y) is total billed water. Productive inputs are labor (l), third-party services (t), capital (k) and "materials and others" (o). In order to distinguish between production density, customer density and economies of scale we included total water connections (Cx) and served localities (Lc) into the regression.[13]

The price of labor (w_l) is the average monthly salary calculated as the ratio between labor expenses and staff as reported by SUNASS. The price of third-party services (w_t) is the ratio between expenses of outsourced activities (from cleaning and security services to repairs) and volume. The cost of capital (w_k) is the sum of the fixed asset depreciation rate and the weighted average cost of capital (WACC). We take the values of cost of capital from Chapter 9 if each Tariff Study (they are expected values in Peruvian *soles* for a five-year period) and convert them to current values by replacing the expected values of risk free rate, country risk premium, share of debt and devaluation rate with their respective observed annual values.[14] Lastly, the price of "materials and others" (w_o) is calculated as the ratio between expenses in energy, chemicals, fuels, etc. and volume of total billed water.

In addition, we add control variables to capture differences in total costs arising from service quality, and from technical, operational or geographical conditions, generally labeled as environment variables.

SUNASS deems pressure and continuity of water as water quality variables, and the rate of wastewater treatment as sewerage quality variable.[15] In this paper we define service quality in a more comprehensive way by defining five variables: metering, unaccounted-for water, water utilization, sewage treatment and high level of treatment, which are detailed next.

We consider metering as a quality variable because both continuity and good levels of pressure are necessary conditions for its implementation. Metering is defined as the percentage of total connections which are metered (*Meter*). In some cases no metering is present and the value of this variable is zero. Given that metering one connection is similar to no metering at all, we replace zeros by very small values, specifically 10^{-6} (see justification in Greene 2008, pp. 296–7, and Urakami and Parker 2011).

---

[9] We use the median to avoid a potential bias that the biggest SSP (SEDAPAL in Lima) could drag on mean values. This procedure is also used in Filippini et al. (2008).

[10] See Resolution 010-2006-SUNASS-CD.

[11] Data available in http://www.sunass.gob.pe/websunass/index.php/sunass/supervision-y-fiscalizacion/indicadores-de-gestion/indicadores-promedio.

[12] See http://www.sunass.gob.pe/websunass/index.php/eps/estudios-tarifarios.

[13] We tried three alternatives to measure Lc. The first measure was served surface (in square kilometers), which would have been the best option, but full data was unavailable. The second measure was network length but this variable was highly correlated with connections. The third measure was the number of localities (as reported by the Tariff Studies).

[14] Information on risk free rate and country risk premium is available in Section 37 of http://www.bcrp.gob.pe/estadisticas/cuadros-de-la-nota-semanal.html and the evolution of the exchange rate Soles/Dollar is available in Section 41. The share of debts is the ratio between debts and debts + equity, obtained from annual benchmarking reports by SUNASS.

[15] See SUNASS—Informe 0278-2014/SUNASS-120-F.

Table 2 Descriptive statistics

Variable	Unit of account/definition	Source	N	Mean	s.d.	Min	Max
Dependent variable							
C	Total annual cost (millions of soles)	IG—4.1, 4.2	195	44.30	179.00	0.99	1440.00
Outputs							
y	Volume (millions of m3/year)	IG—2.4	195	18.40	64.60	0.96	421.00
Cx	’000 connections	IG—5.2	195	71.43	195.14	4.34	1317.66
Lc	Towns served	ET—1.2	195	5.74	8.97	1.00	45.00
Input prices							
w_l	Soles/staff/month	IG—5.9	195	2,355.48	962.41	693.35	7279.15
w_t	Soles/y	IG—5.10	195	0.33	0.26	0.04	2.42
w_o	Soles/y	*	195	0.35	0.20	0.00**	1.33
w_k	(WACC + Depreciation rate of Fixed Assets) in %	ET—9 IG—4.2	195	0.09	0.05	0.00**	0.20
Environment variables							
Loss	% unaccounted for water	IG—5.1	195	0.46	0.14	0.07	0.75
Uti	% capacity utilization	ET—1.2	195	0.75	0.18	0.34	1.27
Meter	% metering	IG—5.2	195	0.39	0.28	0.00	0.93
d_treat	Dummy treatment	IG—1.5	195	0.53	0.50	0.00	1.00
d_treat_60	Dummy treatment >60 %	IG—1.5	195	0.27	0.45	0.00	1.00
Dummies							
d_surf	Dummy surface water	IG—5.7	195	0.38	0.49	0.00	1.00
d_und	Dummy underground water	IG—5.7	195	0.13	0.34	0.00	1.00
Forest	Dummy region (forest)	SUNASS	195	0.23	0.42	0.00	1.00
Mountain	Dummy region (mountain)	SUNASS	195	0.36	0.48	0.00	1.00
Shares on cost							
sh_t_g_l	% Labor expenses on costs	IG—5.9	195	0.33	0.10	0.08	0.59
sh_t_g_t	% Third-party services on costs	IG—5.10	195	0.17	0.09	0.02	0.72
sh_t_g_o	% Other expenses on costs	***	195	0.20	0.08	0.00**	0.64
sh_t_g_k	% Capital expenses on costs	****	195	0.30	0.15	0.00**	0.69

Source: Authors’ own calculations based on data from SUNASS and *Instituto Nacional de Estadística e Informática* (INEI). Soles: local currency (exchange rate measured as S$/dollar was close to 3 in December 2014). *Min* minimum, *Max* maximum, *s.d.* standard deviation. Notes: * Difference between Total Cost (*C*) and other input expenses divided by cubic meters billed. ** Round numbers (in all cases the minimum value is positive but <0.005). *** Residual category. **** (WACC + Fixed assets depreciation rate) × Fixed assets/total cost

Unaccounted for water, or network losses (*Loss* variable), allows us to approximate the greater operational expenses when leakages in the network occur or commercial losses arise due to clandestine connections or poorly working meters. This variable is the difference between produced water and billed water (as a percentage of production). SUNASS considers unaccounted (for) water as an indicator of management efficiency but Destandau and García (2014) consider it as a service quality variable that indicates the level of system maintenance. Recall the alternative interpretation of unaccounted for water as output by Corton (2011).

An additional problem in Peru concerns the continuity and pressure of water, which is not guaranteed 24 h a day. A SSP could eventually produce beyond capacity in order to avoid service interruption or lower levels of pressure, but in this case it would overtax quality and sustainability of W&S infrastructure. We measure overcapacity to provide demand (and demand fluctuations) as the ratio between water produced and production capacity (*Uti*).

Sewerage service quality is measured by SUNASS as the percentage of wastewater treatment, capturing the environmental damage of service provision. When applying this concept to our estimation we found out that no treatment had taken place in 47 % of the observations. A possible correction could be the replacement of zeros with very low positive values. However, as opposed to metering, the treatment of a cubic meter of wastewater would require a treatment plant, which would carry significant costs relative to metering one unit in an existing water network. Therefore, we followed a different approach and considered zero treatment as a discrete choice and defined two dummy variables to capture treatment activities: the first one identifies whether a SSP has wastewater treatment (*d_treat*) implying the existence of a treatment plant; the second one accounts for coverage (or importance) and takes value of 1 if treatment exceeds 60 % of the wastewater volume collected (*d_treat_60*).[16] This way, treatment is a dummy variable that shifts total costs by a certain amount but does not change with quantity.

The set of dummy variables is completed by two dummies to account for water source and another two dummies to account for geographical characteristics. Raw water could come from surface or underground sources, with the first source requiring more treatment but less energy and vice versa. Following Filippini et al. (2008), we constructed two dummy variables: *d_sup* takes value of 1 if the only source is surface; *d_und* takes value of 1 if water comes exclusively from underground sources. The base case is that SSPs extract water from both sources, in which case we would expect a reduction in costs as long as SSPs have the option to minimize extraction costs.

Finally, Peru is divided in three different W&S regions: the Coastal ("*Costa*") region is arid with the exception of the northern area, which has a tropical climate; the Mountain ("*Sierra*") region has cold snow-capped highlands with abundant water resources; and the Forest ("*Selva*") region is characterized by tropical jungles. Given that the W&S industry is highly dependent on geographical conditions we capture differences in regional costs by using two dummy variables *Forest* and *Mountain*, taking the Coastal region as the base case (Corton 2011, also makes this distinction).

6 Results and economies of scale in W&S

6.1 Results

Table 3 presents the estimates of the model based on the system of Eqs. (8)–(9).

The goodness of fit of this model is high, with R squared equal to 0.98. The Breusch-Pagan test to the SUR regression (of independence of equations) rejects the null hypothesis meaning that the (contemporaneous) errors associated with the dependent variables are correlated and the disturbance covariance matrix is not diagonal, which confirms this procedure of estimation.

The coefficients of output and factor prices are all positive, ensuring monotonicity. Concavity is satisfied in 53 % of the cases; close to the values found by Baranzini and Faust (2009) Urakami and Parker (2011) and Destandau and García (2014).

All first-order coefficients are statistically significant at the 5 % level and have the expected sign. A 1 % increase in water billed raises costs by only 0.42 %. Economies of production density valued at the median are 2.38. Increasing the number of connections or served localities raises costs by 0.55 and 0.06 %, respectively. These values imply economies of customers density of 1.03 and economies of scale of 0.97, respectively (valued at the median).

Estimates of price coefficients are in line with cost shares values in Table 2. Besides, all second order coefficient are positive, implying a positive relationship between input price and input's share in cost.

The effects of quality variables are reasonable. First, a 1 % increase in network losses adds 0.17 % to costs, while a 1 % increase in metering rate adds 0.08 % to costs. In particular, a reduction in water losses generates costs savings at a decreasing rate and more metering has a positive and increasing impact on cost. Second, with regards to utilization capacity the linear coefficient is not significant and the second order coefficient is significant and negative. That implies a non-linear and concave relationship between utilization rate and cost. That is, the cost function moves downwards as utilization rates depart from the median. Third, sewage treatment has no significant impact on costs unless treatment is above 60 %, in which case costs increase by 9 %.

Water source dummies indicate that SSPs with access to surface and underground water do not save costs from shifting sources towards the cheaper one. However, extraction costs for SSPs with only surface water are 15 % higher than extraction costs for SSPs with underground water. Finally, regional variables indicate that provision in the Forest and the Mountain is on average 10 and 7 % cheaper than in the Coastal region, respectively.

We tested alternative functional forms in order to verify whether the cost structure of W&S in Peru could be characterized with more parsimonious models. We assessed three reduced functional forms (with particular constraints between brackets):

- Cobb-Douglas ($\beta_{yy} = \gamma_{ij} = \gamma_{ym} = f_{ij} = h_{ml} = 0$ for $i, j = \{l, o, k\}, m = 1,\ldots, M$, and $l = 1,\ldots, L$). Under this

---

[16] There are three varieties of treatment that are increasingly costly given their complexity and the volume to treat: primary treatment (solid sedimentation), secondary treatment (the solidification of dissolved organic material) and tertiary treatment (ponds, microfiltering or disinfection). Unfortunately, available information does not allow us to distinguish among them so we assumed treatment was the same across SSPs.

Table 3 Empirical cost model for Peru W&S

Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
y	0.420***	$Loss^2$	0.305**	d_surf	0.148***
Cx	0.547***	Loss*Uti	0.277**	d_und	0.011
Lc	0.064**	Loss*Meter	−0.027	d_treat	−0.044
p_l	0.337***	Uti^2	−0.790***	d_treat_60	0.094***
p_o	0.213***	Uti*Meter	−0.096**	Forest	−0.102**
p_k	0.280***	$Meter^2$	0.018**	Mountain	−0.073***
Loss	0.169**	p_l^2	0.108***	Constant	17.274***
Uti	−0.055	p_l*p_o	0.000		
Meter	0.088***	p_l*p_k	−0.054***		
y^2	−1.102***	p_l*Cx	0.018		
y*p_l	−0.042*	p_l*Lc	0.001		
y*p_o	0.017	p_l*Loss	−0.027*		
y*p_k	−0.003	p_l*Uti	0.010		
y*Cx	1.074***	p_l*Meter	−0.007**		
y*Lc	−0.033	p_o^2	0.025***		
y*Loss	−0.474**	p_o*p_k	−0.000		
y*Uti	0.351	p_o*Cx	−0.027		
y*Meter	−0.044	p_o*Lc	0.002		
Cx^2	−1.026***	p_o*Loss	0.034***		
Cx*Lc	0.105	p_o*Uti	−0.008		
Cx*Loss	0.607***	p_o*Meter	−0.002		
Cx*Uti	−0.317	p_k^2	0.087***		
Cx*Meter	0.015	p_k*Cx	0.030		
Lc^2	−0.154**	p_k*Lc	−0.006		
Lc*Loss	−0.004	p_k*Loss	−0.003		
Lc*Uti	−0.170*	p_k*Uti	−0.024		
Lc*Meter	0.010	p_k*Meter	0.013***		
Observations: 195		Parameter: 60		R^2: 0.98	

Source: Own calculation. Asterisks represent the significance of the standard error robust coefficients: *** $p < 1$ %, ** $p < 5$ %, * $p < 10$ %. Breusch–Pagan: $\chi^2(6) = 242.177$, Pr = 0.0000

functional form, the cost function depends on the direct effect of each variable, and elasticities are constant throughout the sample.

- Hedonic[17] ($\lambda_i = f_i/\beta_y = f_{yi}/\beta_{yy} = f_{ji}/f_{yj} = h_{mi}/\gamma_{ym}$, for $i, j = \{loss, uti, meter\}$ and $m = \{l, o, k\}$). This representation tests whether quality variables and utilization rate are independent of the rest of the variables.[18]
- Homothetic ($\gamma_{yl} = \gamma_{yo} = \gamma_{yk} = 0$). Under this specification the technology is $C(y, w, z) = h(y, z) * c(w, z)$, so that the output elasticity is independent of relative input prices.

Table 4 compares the four models. Likelihood tests reject the alternatives with a confidence level higher than 95 %.

6.2 Economies of production density, customer density and scale

We use estimates of Table 3 to fit the definitions of economies of production density, customer density and scale defined in Eqs. (2)–(4). Table 5 presents these estimates for different percentiles assuming that values of output, connections and localities correspond to that percentile and everything else remains constant.

Economies of production density are present all along the sample. This implies that costs increase less than

---

[17] The cost specification from Eq. (5) assumes that quality and environmental variables enter directly into the cost function and they interact with the remaining arguments. Conversely, the hedonic approach defines a cost function as $C = C(\phi(y, q), w, e)$, where y is the output, q is the quality attributes vector $q_l = q_1, \ldots, q_L$ and e is the set of environmental variables $e_r = e_1, \ldots, e_R$, thus $z = \{q, e\}$ (Zoric, 2006). This makes it necessary to separate the arguments of ϕ from other explanatory variables. Hence, the quality-adjusted output is represented as $\ln \phi = \ln y + \sum_l \lambda_l \ln q_l$.

[18] Given that the constraints imposed in this case are non-linear, we estimate the non-linear SUR model.

Table 4 Constraint Tests

Variable	Model 1 translog	Model 2 Cobb-Douglas	Model 3 hedonic	Model 4 homothetic
Parameters	60	15	37	57
R^2	0.9800	0.9690	0.9708	0.9796
LR χ^2 (60-parameters)		1965.91	105.21	8.05
Prob > χ^2		0.0000	0.0000	0.0450

Source: Own calculation

Table 5 Economies of production density, customer density and scale (by percentiles)

	10th percentile	25th percentile	Median	75th percentile	90th percentile
Production density (E_{PD})	2.543	1.585	2.381	2.372	2.707
Customer density (E_{CD})	1.165	1.139	1.034	0.994	0.882
Economies of scale (E_S)	1.008	0.937	0.970	0.919	0.948

Source: Own calculation based on results from Table 3

Table 6 Economies of production density, customer density and scale (by region)

	Coastal	Mountain	Forest	Median
Production density (E_{PD})	1.637***	5.298**	2.172***	2.381
Customer density (E_{CD})	0.973**	1.094***	1.060***	1.034
Economies of scale (E_S)	0.927***	0.972***	0.946***	0.970

Source: Own calculation based on results from Table 3. *Stars* refer to one-sample t test to evaluate whether economies of production density, customer density or scale are different from 1. This is Ho: mean = 1. Confidence levels are *** $p < 1$ %, ** $p < 5$ %, * $p < 10$ %

proportionally with output when connections and localities remain constant. These economies seem to have a U-shape with a minimum (and hence lowest cost savings) around the 25th percentile.

The joint effect of production and connections produces a strong reduction in economies of customer density. Under this definition, economies are present approximately until the 75th percentile, turning to diseconomies at higher percentiles.

The full effect of production, connections and served area provides the main finding of this paper: that diseconomies of scale are present throughout most of the sample (with the exception of the 10th percentile). Under this definition, costs saving from increasing localities would be present only around the 10th percentile. However, for percentiles higher than the 10th we see that values do not decline steadily but remain within a range of 0.92 and 0.97 indicating slight increasing average costs.

In general terms, our results are consistent with the literature focusing on total cost economies of scale (Filippini et al. 2008; Mizutani and Urakami 2001; Saal and Parker 2000; Saal et al. 2007, and SCL Econometrics 2009). Economies decrease as our focus moves from production density, to customer density and to scale. In particular, Mizutani and Urakami (2001), Saal and Parker (2000) and Saal et al. (2007) do not find long-run economies of scale.

In Sect. 4 we mentioned that Corton (2011) analyzed economies of scale for Peru using a definition similar to "economies of production density" in this paper. The elasticities in that paper are 1.58, 1.74 and 1.81 for the Coastal, Mountain and Forest regions, respectively. In order to compare our results with Corton's, Table 6 presents the economies of production density, customer density and scale, distinguishing the size and region of SSP.[19]

By region, elasticities of production density are 1.64, 5.30 and 2.17 for Coastal, Mountain and Forest regions, respectively. The greater values for Mountain and Forest are reasonable: SSPs can easily reduce costs as long as water production does not require extra connections or areas. However, when expansion incorporates new connections, cost savings begin to wane to the point of becoming nonexistent when adding new localities. While the estimate of economies of production density for the

---

[19] We follow Filippini et al. (2008) in stacking input prices at their median values, letting the other variables take their actual values.

Coastal region is similar to Corton's, we find higher values for Mountain and Forest regions.[20]

From Sect. 6.2 we highlight the importance of detailing the drivers of output expansion (production, customers or areas). Consolidation of SSPs under Corton's model would be fostered in all regions, but this recommendation is not as clear when identifying additional components of the output vector (customers and areas). Specifically, the effect of consolidation of SSPs on costs will vary on a case by case basis. We concentrate on this policy question in next section.

6.3 Economies of scale and policy implications

Bear in mind that the authorities in Peru expect to benefit from economies of scale by extending the scope of SSPs from main urban areas to the whole territory and in doing so consider two cases: (1) the expansion of service provision to areas currently not covered by the corresponding SSP and (2) a consolidation of SSPs at supra-provincial or regional level. Among the possible options to implement the policy, SUNASS suggests: (1) mergers of SSPs, (2) extension of SSP coverage to areas served by local Sanitation Services Boards, (3) extension of SSP coverage to areas served by rural providers, among others.

As regards the first option –service expansion to areas currently not covered by the existing SSP– economies of customer density provide a guide in this direction as long as expansion does not extend to other cities or towns. Tables 5 and 6 show that there is room for reduction in average costs by increasing customers in small and medium SSPs or providers located in the Mountain or Forest regions. The same applies for integration of urban areas served by Sanitation Services Boards or Specialized Operators. If the service expansion requires an increase in the number of territories, then the proper measure to assess cost savings is "economies of scale". From the general results in Tables 5 and 6 cost saving from consolidation can only be achieved by the smallest SSPs.

To illustrate the second option, that is to say the possibility of SSPs consolidation through M&A, we first computed economies of scale for each SSP in the last year of our sample (2010) and selected the cases with economies of scale (7 out of 39 SSPs). Then we identified the department in which these SSPs provide services and looked for consolidation with other SSPs within the same department. For the *ex ante* case we used the value of cost adjusted from the regression rather than the real cost value. The *ex post* cost of the consolidated firm was calculated replacing prices and environmental variables in the equation, averaging them using relative output of the *ex ante* units as weights. This way, changes in costs do not carry differences between *ex ante* real costs and adjusted costs.

In only one case it is possible to consolidate two SSPs with economies of scale, with costs savings of 9.5 %.[21] On the other hand, the consolidation of two SSPs, one of them with diseconomies of scale, may save or increase costs depending on the relative economies-diseconomies of individual SSPs and their relative sizes.[22]

7 Conclusions

This paper quantifies economies of scale in the provision of water and sanitation services in Peru's urban areas. We distinguish increases in volumes, connections, and served areas to define economies of production density, customer density and scale.

We first find that the W&S sector in Peru presents strong economies for production density, lower but still positive economies of customer density and slight diseconomies of scale at the median levelThese results are consistent with those found in W&S sanitation literature in general, and with the Peruvian case in particular. Second, economies are characterized by SSP size and geography: economies of production density remain high throughout the sample; economies of customer density are present in small and medium size SSPs; and economies of scale are only present in the smallest SSPs. On the other hand, economies of customer density and scale are quite similar across regions. Third, we identify some cases with a potential margin to reduce average provision costs via suitable mergers. On the one hand, there is room for reduction in average costs by increasing customers in small and medium SSPs or providers located in the Mountain or Forest regions. On the

---

[20] There are at least four differences that may explain the result: the sample period, the number of SSPs, the estimation procedure, and the controls used in the regressions. Checking all these differences is beyond the scope of the paper.

[21] This case corresponds to the Forest SSP EMAPA San Martin (economies of scale of 1.037) and EMAPA Moyobamba (1.052) with cost savings of 9.3 %.

[22] For example, a merger between EMAPA San Martin (1.037) and SEDAPAR (0.943) would result in a 2 % reduction in costs (SEDAPAR weighs 83 % of the consolidate SSP); but a merger between EMAPA Moyobamba and SEDAPAR would result in a slightly increase in costs by 0.1 % (in this case SEDAPAR weighs 95 percent of the consolidate SSP).

A merger between EMAPA VIGSSA (1.095) and EMAPISCO (0.943), both from the Ica region, would result in a 2.3 % reduction in costs (EMAPA VIGSSA weighs 30 % of the consolidate SSP); but a merger between EMAPA VIGSSA and SEMAPACH (0.855) would result in a slightly increase in costs by 3.4 % (in this case EMAPA VIGSSA weighs 18 % of the consolidate SSP).

other hand, the effect of SSPs consolidation on average costs vary on a case by case basis: economies of scale is a sufficient condition for consolidation, although there are a few practical cases (in which case, cost savings around 9 %); while other cases of consolidation will depend on the relative size of economies/diseconomies and relative size of providers. These results may be useful to anticipate the effects of consolidation-related regulation in W&S in Peru.

Acknowledgments We thank the thorough review of two anonymous referees. An early version of this paper was part of Augusto Mercadier's MA Dissertation at Universidad Nacional de La Plata, under Walter Cont's supervision. It was also presented at the annual congress of the "Asociación Argentina de Economía Política". We thank Ricardo Bebczuk, Federica Brenner, Ariel Casarin, Emilio Lentini, Inés Asís del Valle, Joaquín Coleff, Mariana Marchionni, and Guillermo Cruces. The usual disclaimer applies.

References

Abbott M, Cohen B (2009) Productivity and efficiency in the water industry. Util Policy 17:233–244

Antonioli B, Filippini M (2001) The use of a variable cost function in the regulation of the Italian water industry. Util Policy 10:181–187

Ashton J (1999) Economies of scale, economies of capital utilization and capital utilization in the english and welsh water industry. Bournemouth University, School of Finance and Law working paper series, 17

Baranzini A, Faust A (2009) The cost structure of water utilities in Switzerland. Cahier de Recherche No HES-SO/HEG-GE/C–10/5/1

Bhattacharyya A, Parker E, Raffiee K (1994) An examination of the effect of ownership on the relative efficiency of public and private water utilities. Land Econ 70:197–209

Bhattacharyya A, Harris T, Narayanan R, Raffiee K (1995) Specification and estimation of the effect of ownership on the economic efficiency of the water utilities. Reg Sci Urban Econ 25:759–784

Bottasso A, Conti M (2009) Scale economies, technology and technical change in the water industry: evidence from the english water only sector. Reg Sci Urban Econ 39:138–147

Bottasso A, Conti M, Piacenza M, Vannoni D (2011) The appropriateness of the poolability assumption for multiproduct technologies. Int J Prod Econ 130:112–117

Corton M (2011) Sector fragmentation and aggregation of service provision in the water industry. J Prod Anal 35:159–169

Destandau F, García S (2014) Service quality, scale economies and ownership: an econometric analysis of water supply costs. J Regul Econ 46:152–182

Fabbri P, Fraquelli G (2000) Cost and structure of technology in the Italian Water Industry. Empirica 27:65–82

Feigenbaum S, Teeples R (1983) Public versus private water delivery: a hedonic cost approach. Rev Econ Stat 65:672–678

Ferro G, Lentini E, Mercadier A (2011) Economies of scale in the water sector: a survey of empirical literature. J Water Sanit Hyg Dev 1:179–193

Filippini M, Hrovatin N, Zoric J (2008) Cost efficiency and economies of scale of slovenian water distribution utilities: an application of panel data stochastic frontier methods. J Prod Anal 29:169–182

García S, Thomas A (2001) The structure of municipal water supply costs: application to a panel of French local communities. J Prod Anal 16:5–29

García S, Moreaux M, Reynaud A (2007) Measuring economies of vertical integration in network industries: an application to the water sector. Int J Ind Organ 25:791–820

Greene W (2008) Econometric analysis, 6th edn. Prentice Hall, Upper Saddle River

Hayes K (1987) Cost structure of the water utility industry. Appl Econ 19:417–425

Hunt L, Lynk E (1995) Privatization and efficiency in the UK water industry: an empirical analysis. Oxford Bull Econ Stat 57:371–388

Iimi A (2008) (UN) Bundling public–private partnership contracts in the water sector: competition in auctions and economies of scale in operation. Policy research working paper series 4459, The World Bank

Kim H, Clark R (1988) Economies of Scale and Scope in Water Supply. Reg Sci Urban Econ 18:479–502

Kim E, Lee H (1998) Spatial Integration of Urban Water Services and Economies of Scale. Rev Urban Reg Dev Stud 10:3–18

Martins R, Coelho F, Fortunato A (2008) Water losses and hydrographical regions influence on the cost structure of the Portuguese Water Industry. GEMF working papers 2008-06, GEMF—Faculdade de Economia, Universidade de Coimbra

Mizutani F, Urakami T (2001) Identifying network density and scale economies for japanese water supply organizations. Reg Sci 80:211–230

Panzar J (1989) Technological determinants of firm and industry structure. In: Schmalensee R, Willig R (eds) Handbook of Industrial Organization, vol 1. Elsevier Science Publishers B. V, Amsterdam, pp 3–59

Revollo D, Londoño G (2010) Análisis de las economías de escala y alcance en los servicios de acueducto y alcantarillado en Colombia. Universidad De Los Andes-CEDE, Revista Desarrollo y Sociedad

Saal D, Parker D (2000) The impact of privatization and regulation on the water and sewerage industry in England and wales: a translog cost function model. Manag Decis Econ 21:253–268

Saal D, Parker D, Weyman-Jones T (2007) Determining the contribution of technical change, efficiency change and scale change to productivity growth in the privatized English and Welsh Water and Sewerage Industry: 1985–2000. J Prod Anal 28:127–139

Saal D, Arocena P, Maziotis A, Triebs T (2013) Scale and scope economies and the efficient vertical and horizontal configuration of the water industry: a survey of the literature. Rev Netw Econ 12:93–129

Sauer J (2005) Economies of scale and firm size optimum in rural water supply. Water Resour Res 41:1–13

SCL Econometrics (2009) Cuantificación de las economías de escala en el sector sanitario: informe final preparado para Subsecretaría de Economía. Estudio Encargado por el Gobierno de Chile.

Stone & Webster Consultants (2004) Investigation into evidence for economies of scale in the water and sewerage industry in England and Wales. Prepared for OFWAT. Final report

Torres M, Morrison-Paul C (2006) Driving forces for consolidation or fragmentation of the US water utility industry: a cost function approach with endogenous output. J Urban Econ 59:104–120

Tynan N, Kingdom B (2005) Optimal size for utilities? Public policy for the private sector. Note number 283. The World Bank

Urakami T, Parker D (2011) The effects of consolidation amongst japanese water utilities: a hedonic cost function analysis. Urban Stud 48:2805–2825

Walter M, Cullmann A, von Hirschhausen C, Wand R, Zschille M (2009) Quo vadis efficiency analysis of water distribution? A comparative literature review. Util Policy 17:225–232

Zoric J (2006) Cost efficiency and regulation of slovenian water distribution utilities: an application of stochastic frontier methods. Doctoral Dissertation, University of Lugano