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ORIGINAL RESEARCH

Assessing the Quality of Service of Water Companies: a 'Benefit of the Doubt' Composite Indicator

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Abstract

Evaluating the quality of service (QS) provided by water companies is essential to benchmark and regulate them. Composite indicators (CIs) are a useful tool for this as they consist of aggregated multiple performance indicators in a single index, providing a holistic assessment of the QS of water companies. In this study, the novel 'benefit of doubt' methodology was used in order to evaluate the QS of a sample of Chilean water companies, by computing CIs that integrate both direct and reverse indicators. Moreover, the estimation of the Nerlove–Luenberger super-efficiency CI allowed for the ranking of water companies based on their QS. Results showed that, on average, Chilean water companies provide water and sewerage services with high quality, as the mean CI of the QS estimated was 0.93. Nevertheless, the QS of 2 of the 24 water companies evaluated stood out remarkably. The second-stage analysis conducted revealed that the ownership and peak factor of water companies and water consumed by customers affects the QS of water companies. The methodological approach followed in this study to evaluate the QS of water companies would be very useful for water regulators, as the CI computed integrates both desirable and undesirable outputs.

Keywords Benefit of the doubt · Data envelopment analysis · Synthetic indicator · Quality of service · Benchmark · Water industry

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1 Introduction

The Sustainable Development Goals adopted by the United Nations (UN 2015) involve ensuring the availability of water and sanitation for all. In order to meet these development goals, the worldwide water industry faces the challenge of improving the quality of service (QS) they provide (Molinos-Senante et al. 2017). Moreover, since water companies provide services as monopolies, the water regulators play an essential role in defining quality standards, monitoring compliance, and developing policies to encourage improvements in the QS provided by the water companies (Salleh et al. 2019). In doing so, and as part of the regulation of water companies, water regulators benchmark the performance of water companies (Marques 2006). This process involves the definition of a large set of performance indicators (PIs) (Nogueira Vilanova et al. 2015), including QS issues, and comparing the performance among water companies (Gidion et al. 2019).

The definition and monitoring of PIs is very useful for water regulators as it promotes virtual competition among water companies and creates incentives to improve efficiency and QS (Ehrhardt and Janson 2010). However, this approach has some shortcomings: (i) it does not allow for a holistic assessment of the problem (Pinto et al. 2017), (ii) it assumes that all PIs have the same importance, when some of them are more relevant (Molinos-Senante et al. 2017), and (iii) it does not enable the ranking of water companies based on their general performance or QS (Duarte et al. 2009). To overcome these limitations, the literature referenced above proposed the aggregation of PIs into a composite indicator (CI) that provides a multidimensional measure of the performance of water companies (e.g. Storto 2014; Güngor-Demirci et al. 2017; Lombardi et al. 2017). CIs present several benefits, such as the capacity to summarize information, the ability to interpret results as opposed to a battery of PIs, and the capacity to reduce the visible size of a set of PIs without dropping the underlying base information (Nardo et al. 2008; Zanella et al. 2015). Hence, CIs are easier to interpret by policymakers and the general public (Cherchye et al. 2011). Consequently, CIs are being increasingly recognized as a useful tool for policy making in different fields, including urban water management (e.g. Fuentes et al. 2017; Ananda 2018; Arocena et al. 2020).

From a methodological point of view, several multi-criteria decision analysis techniques have been employed to construct CIs (Brink et al. 2020), which in the framework of the water industry focused primarily on evaluating the overall performance of water companies (e.g. Cetrulo et al. 2019; Liu and Fukushige 2020). Thus, in spite of the usefulness of CIs, to the best of our knowledge, only three previous studies employed this approach to assess the QS provided by water companies. Karnib (2015) used a fuzzy inference approach to aggregate four QS indicators, for a sample of water companies in Lebanon. Pinto et al. (2017) aggregated 16 PIs based on the ELECTRE TRI-nC method using the Portuguese water industry as a case study. Finally, Molinos-Senante et al. (2017) employed the data envelopment analysis (DEA) method, to evaluate changes in the QS provided to customers of 19 Chilean water companies.

The use of DEA to construct CIs was proposed by Cherchye et al. (2007). This approach is known as "Benefit of the Doubt" (BoD) and is equivalent to the pioneering DEA model proposed by Charnes et al. (1978), assuming a unitary input level for all units evaluated. Hence, BoD method is very suitable to evaluate the QS of water companies as all PIs embracing the CI are outputs since they reflect the characteristics of the products (water and sewerage services) provided by water companies. DEA is a very suitable method to aggregate PIs into a CI because the PI weighs results from an optimization process based on linear programming and therefore, they are less prone to subjectivity and controversy (Karagiannis and Karagiannis 2018). The CI developed by Molinos-Senante et al. (2017) to evaluate the QS of water companies integrates seven indicators, all of which are considered desirable outputs, i.e., the higher the value of the indicator, the higher the QS of the water company. However, in the evaluation of the QS provided by water companies, there are also reverse indicators, i.e., indicators for which larger values reflect lower performance (Färe et al. 2019). A typical example of reverse indicators, in the framework of water companies´ performance assessment, is non-revenue water because the larger the percentage of non-revenue water, the worse the performance of the water company.

In DEA methodology, reverse indicators are known as undesirable outputs because the aim of the units is to minimize its generation. The integration of undesirable outputs in performance assessment has been considered since the 1980s (Zanella et al. 2015). In doing so, both direct and indirect approaches have been employed. Indirect approaches transform the values of undesirable outputs to allow them to be treated as normal outputs or inputs in traditional DEA models. However, Seiford and Zhu (2002) illustrated that treating undesirable outputs as inputs is incorrect, as it does not reflect the real production process. Alternative indirect approaches, such as the incorporation of undesirable outputs in the form of additive inverses or multiplicative inverses, have been widely criticized (Dyson et al. 2001; Zanella et al. 2015). Hence, the most recent literature on this topic has integrated undesirable outputs, following the direct approach, i.e., treating the undesirable outputs in their original form without requiring any modification to the measurement scale (Chung et al. 1997).

Another positive feature of using the BoD approach to develop CIs is that the units evaluated can be ranked according to their performance (Sahoo et al. 2017). In the framework of regulated industries, such as the water industry, this feature is very relevant since benchmarking is often used for regulatory purposes (Walker et al. 2019). However, it is not possible to rank the set of units (water companies, in this study) whose CI values are equal. This means that the BoD method cannot rank units whose performance is at the maximum, i.e., units whose CI equals one (lo Storto 2018). To overcome this limitation, Andersen and Petersen (1993) proposed a modification of the conventional DEA model to estimate the super-efficiency of the efficient units, i.e., of units whose performance is at the maximum compared to their peers. Subsequently, and to avoid infeasibility problems, several methodological alternatives have been proposed (e.g.Lovell and Rouse 2003; Chen 2004; 2005; Ray 2008) to compute super-efficiency scores.

Against this background, the objectives of this study are threefold. The first is to evaluate the QS of a sample of water companies, embracing both desirable and undesirable outputs. In doing so, a CI was built for each water company based on the BoD methodological approach. The second objective is to rank the sample of water companies evaluated, based on their QS, by computing the Nerlove–Luenberger super-efficiency scores, since they are unique, easily interpreted, and yield a complete ranking of the water companies in the sample (Ray 2008). The third objective is to explore exogenous variables that might affect the QS of water companies. The empirical application focused on a sample of 24 water companies that provide both water and sewerage services in Chile.[1]

This paper contributes to the current literature by evaluating, for the first time, the QS of water companies, using CIs which integrate not only desirable outputs but also undesirable

[1] For a further description of the Chilean water industry, see Sect. 3.1 "Description of the Chilean water industry".

outputs. The super-efficiency assessment conducted is also a pioneering approach, in the context of water companies, ranking them according to their QS. This information is very relevant for water regulators for improving the QS of water companies by benchmarking, and therefore, protecting the interest of customers and incentivising competition. Moreover, no previous studies have explored the potential relationship between exogenous variables and the QS of water companies. Hence, this study also contributes to the literature on this topic.

2 Methodology

To estimate the CI, relative to the QS, of each water company evaluated, the BoD approach was employed. Based on previous studies (e.g. Rogge 2012; Gaaloul and Khalfallah 2014; Färe et al. 2019; Pérez et al. 2019; Gulati et al. 2019), all QS indicators were specified as desirable and undesirable outputs and an identical input level, which was assumed to be equal to one, was specified for all water companies evaluated. The extension of the directional distance function proposed by Chung et al. (1997) was employed as it allows for simultaneous expansion of desirable outputs and contraction of undesirable outputs, according to a directional vector, while keeping inputs fixed. In particular, the CIs were computed using the BoD DEA model proposed by Zanella et al. (2015). A limitation of this methodology is the lack of robustness of the performance (QS index in this study) estimates. Due to the deterministic nature of the BoD method, the CIs estimated does not consider the impact of operating variables. To overcome this limitation, Rogge et al. (2017) and Fusco et al. (2020) adjusted the directional BoD model proposed by Zanella et al. (2015) according to insights from the robust and conditional "order-m" model proposed by Cazals et al. (2002). This methodological approach allows accounting for the exogenous conditions of the units evaluated by comparing only like with likes (Rogge et al. 2017). In particular, the conditional version of the BoD-model only compares each unit with units that operate under similar background conditions (Fusco et al. 2020). This is done by executing a Monte Carlo simulation procedure in which B iterations are performed. Firstly, m units with similar operating conditions are drawn (with replacement) from the full sample of units. Subsequently, the directional distance BoD-model is applied (Rogge et al. 2017). The conditional BoD model allows for non-parametric statistical influence of the relationships between the exogenous variables and the estimated composite score. In spite of this notable advantage, the relatively low number of water companies evaluated in this study (see Sect. 3) did not allow us to apply the robust conditional order-m BoD model because it was not possible to define m groups of water companies operating with the same background characteristics.

The BoD DEA model employed (Zanella et al. 2015) is as follows:

$$D_o(y_o, b_o, g_o^y, g_o^b) = \text{Max } \beta \tag{1}$$

s.t.

$$\sum_{k=1}^{k} \lambda_k y_{km} \geq y_{0m}(1+\beta) \quad m = 1, \ldots s$$

$$\sum_{k=1}^{k} \lambda_k b_{ki} \leq b_{0i}(1-\beta) \quad i = 1, \dots l$$

$$\sum_{k=1}^{k} \lambda_k = 1$$

$$\lambda_k \geq 0 \quad k = 1, \dots, k$$

where y_{km} are the desirable outputs produced by the water company,k b_{ki} are the undesirable outputs produced by the water company, k and and λ_k are the intensity variables. The factor β indicates the extent of the water companies´ performance, which in our case corresponds to the CI, relative to the QS of the water company k. β ranges between zero and one, where the value of one corresponds to the best level of performance observed in the sample. In other words, water companies whose β value (CI) is equal to one present the best QS when compared to their peers. The difference between the CI (β) and the value of one is the potential room for each water company to improve its QS.

According to Zanella et al. (2015), the restrictions of Eq. (1) ensure that a water company will only be considered efficient, i.e., with the best QS, when no further improvements to both desirable and undesirable outputs are possible. However, this methodological approach does not allow the ranking of water companies whose CI equals one. To overcome this limitation, past research (e.g. Andersen and Petersen 1993; Lovell and Rouse 2003; Chen 2004, 2005) computed the super-efficiency of the units. Basically, a unit is considered super-efficient if its DEA efficiency score exceeds the value of one, when measured against a production possibility set constructed from the data of all other units in the sample. Taking into account that in this study, the CIs were estimated using the directional distance function (Eq. 1), the Nerlove–Luenberger measure of super-efficiency proposed by Ray (2008), was employed to rank the water companies whose CI equals one.

The DEA model for computing the Nerlove–Luenberger super-efficiency of the water company k is as follows (Ray 2008):

$$D_o(y_o, b_o, g_o^y, g_o^b) = \text{Max } \beta \tag{2}$$

s.t.

$$\sum_{\substack{j=1 \\ j \neq k}}^{k} \lambda_j y_{jm} \geq y_{km}(1+\beta)$$

$$\sum_{\substack{j=1 \\ j \neq k}}^{k} \lambda_j b_{ji} \leq b_{ki}(1-\beta)$$

$$\lambda_k \geq 0$$

If a water company is super-efficient, $\beta > 1$ Eq. (2). Between two water companies, both the super-efficient one and the one with a larger value of β, is ranked higher in terms of performance (QS in this study).

In order to identify the factors affecting the QS of water companies, a second-stage analysis was conducted. In doing so, several studies, use either ordinary least squares (OLS) or tobit regressions. However, this procedure suffers the following shortcomings: (i) the process to generate the data has not been described in most of the studies (Simar and Wilson 2007); (ii) efficiency scores (QSI in this study) are censored and therefore, OLS approach is not appropriate (Grosskopf 1996); (iii) if the variables selected for the second stage are expected to affect QS, they should be included in the first stage of analysis; (iv) the variables used in specifying the original efficiency model are correlated with the exogenous variables used in the second stage, then the second stage estimates will be biased; and (v) erroneous results can be obtained mainly due to the serial correlation between the error term and the set of covariants in the second stage (Simar and Wilson 2007). Alternative methodologies have been proposed to evaluate the impact of exogenous variables on efficiency scores. For example, Daraio and Simar (2005) applied non-parametric smoothed regression of the ratios between the order-m conditional efficiencies and the unconditional efficiencies (Fusco et al. 2020). Alternatively, Simar and Wilson (2007) and Badin et al. (2014) proposed to use semi-parametric bootstrap approach to evaluate the influence of exogenous variables on efficiency scores.

Since CIs were computed using the BoD DEA method, which is a non-parametric technique, a non-parametric statistical approach was employed. Nevertheless, it should be noted that non-parametric tests are not able to single out differences if the null hypothesis is rejected. Moreover, this approach tests only for differences that are collectively significant (Chan and Walmsley 1997). Following past research (e.g. Dong et al. 2017; Sarra et al. 2017; Guerrini et al. 2017), a hypothesis test approach was employed. In doing so, first, water companies were grouped based on certain exogenous variables that could affect their QS. Second, a hypothesis test was conducted to assess whether there were statistically significant differences among groups of water companies, according to the variable under scrutiny. In particular, the Mann–Whitney *U* and Kruskal–Wallis non-parametric tests were applied to test the hypotheses. Both tests are similar to the traditional one-way analysis of variance (ANOVA), but without assuming a normal distribution. The null hypothesis (H_0) states that the *K* samples were derived from the same population. If H_0 is true, then the distribution of the QS index, among groups of water companies, is not statistically significant. H_0 can be rejected with a 95% level of significance if the *p*-value is equal to or less than 0.05.

3 Case Study

The empirical application conducted in this study focused on evaluating the QS provided by 24 Chilean water companies in 2017, which provided both water and sewerage services to more than 90% of the urban population in Chile (SISS 2020). Information about the initial set of indicators is available at the Superintendencia de Servicios Sanitarios (SISS[2]) webpage.

[2] Superintendencia de Servicios Sanitarios (SISS) is the Chilean national urban water regulator.

3.1 Description of the Chilean Water Industry

The institutional and regulatory framework of the water and sewerage sector in Chile is different for urban and rural settings, as a result of several reforms carried out across time. In rural areas, the infrastructure to supply drinking water is funded, since 1964, by the Public Works Ministry, and its administration, operation and maintenance is licensed to local committees and cooperatives for an indefinite time period. In contrast, in urban areas, water and sewerage services are provided by water companies, most of which are private and regulated by a national urban water regulator (SISS), which was created in 1990 (SISS 2020). Urban water companies provide drinking water and sewerage services to more than 75% of the Chilean population. Hence, the empirical application conducted in this study focused on urban water companies.

Three main features characterize the Chilean water industry. First, all water companies provide both drinking water and sewerage services, i.e., they conduct all activities involved in the urban water cycle. This issue is relevant for choosing the initial battery of indicators, to evaluate the QS of Chilean water companies, since indicators relative to both water and sewerage services should be included in the assessment. The second issue concerns the diversity of water companies' ownership. The privatization of the Chilean water industry was conducted between 1998 and 2004 following two approaches. In the first period (1998–2000), a significant part of the water companies´ capital was privatized, i.e., public water companies sold strategic shares in participation to private consortia, thereby creating full private water companies. Subsequently, between 2001 and 2004, most of the public water companies were privatized via concession forming concessionary water companies that have the exclusive right to provide water and sewerage services for a period of 30 years (Molinos-Senante and Sala-Garrido 2016; Molinos-Senante et al. 2018). As a result of the privatization process, 96.1% of the urban customers are currently supplied by private water companies (full private and concessionary) and only 3.9% by a public water company, cooperatives, or communities of owners (SISS 2020). Finally, the third distinctive feature of the Chilean water industry is the regulatory model applied to set water tariffs. It is based on the definition of a hypothetically efficient water company. Under this approach, the costs of the "real" water company are compared with a virtual, efficient water company known as the "model" water company, which is considered to be the benchmark (Marques 2010). This model corresponds to a water company without assets, which must make the investment to provide water and sewerage services and establish a development investment plan every five years (Donoso 2017). This regulatory model does not integrate the QS of the water companies in the process of setting water tariffs. In contrast, the regulation of the QS is carried out based on an indirect approach, i.e., the urban regulator establishes penalties in the case of infractions to the parameters and thresholds defined by it. Hence, it is important to evaluate the QS of Chilean water companies.

3.2 Selection of Quality of Service Indicators

According to previous studies (e.g.Marques et al. 2014; Kamarudin et al. 2016; Pinto et al. 2017; Sala-Garrido et al. 2019), there is no single set of valid indicators to evaluate the QS provided by water companies. Nevertheless, the indicators most relevant to the water industry were evaluated for the purpose of this study. Moreover, the selection of the initial indicators is strongly related to the availability of statistical data (Blancas et al. 2011).

According to these criteria, three variables were considered in the assessment as desirable outputs (investment compliance; investment to improve the QS; network reposition) and four as undesirable outputs (non-revenue water; interruptions of water supply; obstructions in the sewerage network; payment accuracy). A brief description of each indicator is given below:

Investment Compliance: Percentage of investment compliance committed in the development plan of the water company. As reported in Sect. 3.1., the Chilean regulatory model mandates that each water company must develop an investment plan that commits to a work plan, to ensure the provision of water and sewerage services.

Investment to improve the QS: Investment conducted to improve the QS of both water and sewerage services, expressed in Chilean Pesos (CLP[3]) per customer. It includes different topics such as improvements in drinking and wastewater treatment plants, implementation of new water meters, etc.

Network reposition: Percentage of reposition of water and sewerage networks. The average reposition rate of the water and sewerage networks of Chilean water companies is 0.49% and 0.22%, respectively (SISS 2020), which means that more than 200 years are required to replenish the water and sewerage networks, which is larger than their useful life affecting the QS provided by the water companies.

Non-revenue water: This is defined as the percentage of supplied water that is unbilled (involves physical and commercial water losses). This variable is very relevant for the Chilean water industry, as its average value is 33.0% (29.04% for the water companies evaluated) and has remained unchanged over time (SISS 2020).

Interruptions of water supply: Interruptions of water supply were measured as the percentage of customers affected by unplanned water supply interruptions.

Obstructions in the sewerage network: Obstructions in the sewerage network are measured as the percentage of customers of the water company affected by this operational problem. The discontinuity in both water and sewerage services is associated with several factors, such as infrastructure age, lack of adequate management, and the occurrence of extreme natural events (e.g. tsunami, earthquake, floods, etc.).

Payment accuracy: The Chilean General Law of Sanitation Services establishes that customers must be charged based on the drinking water consumed and measured through individual metering. Water companies have the obligation to reimburse customers the payments associated with improper or erroneous charges. Hence, the percentage of bills refunded was defined as an indicator of payment accuracy.

Table 1 shows the main descriptive statistics for the variables[4] used in this study for Chilean water companies for 2017.

[3] On 25th February 2020, the conversion rate was: 1 USD ≈ 810 CLP; 1 € ≈ 880 CLP.

[4] An alternative set of initial indicators can be used depending the on the objectives of each empirical application.

Table 1 Main descriptive statistics

	Desirable outputs			Undesirable outputs			
	Investment compliance (%)	Investment in quality of service (CLP/customer)	Network reposition (%)	Non-revenue water (%)	Customers affected by water supply interruptions (%)	Customers affected obstructions in sewerage network (%)	Bills refunded (%)
Average	85.33	92,349	0.76	29.37	36.23	19.90	1.37
Std. Dev	27.00	114,855	0.66	9.22	20.73	24.97	2.05
Minimum	5.00	18,518	0.00	10.80	8.03	0.00	0.20
Maximum	100.00	593,796	2.29	46.14	82.09	91.05	10.41

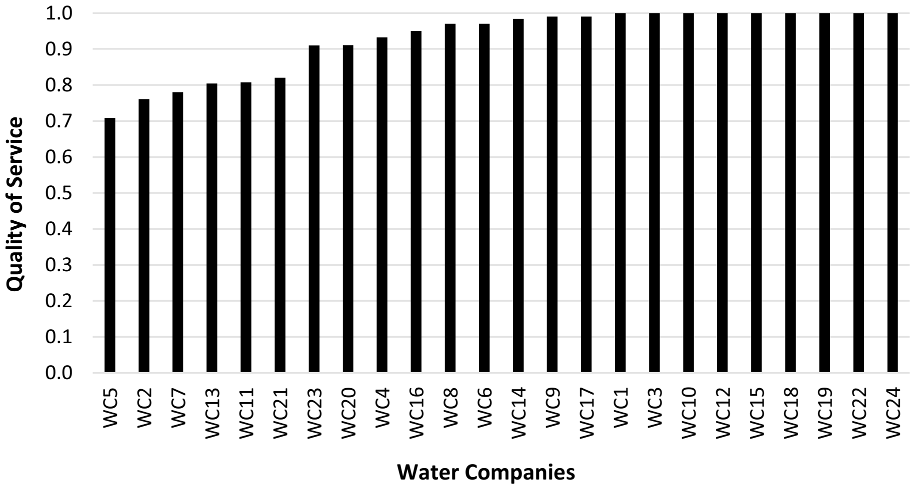

Fig. 1 Composite indicator of quality of service for Chilean water companies based on efficiency model

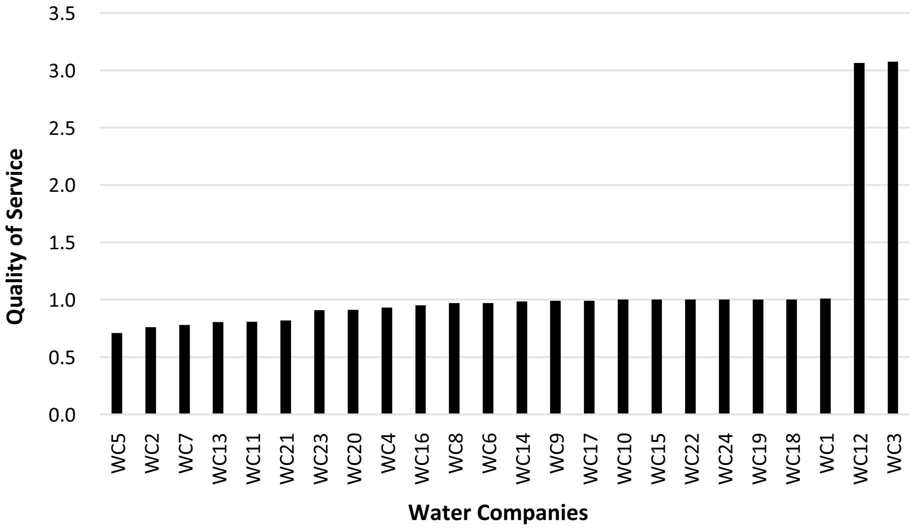

Fig. 2 Composite indicator of QS for Chilean water companies based on super-efficiency model

4 Results and Discussion

4.1 Quality of Service Assessment

To evaluate the QS of the 24 Chilean water companies analysed, Eq. (1) was solved for each water company. Figure 1 shows the CIs estimated for each water company. The mean value of the CIs estimated was 0.93, which indicates that the Chilean water and sewerage industry provided, on average, high QS. This figure indicates that, on average, water companies could improve their QS by 7%. The minimum CI of QS was 0.70, which indicates that Chilean water companies display moderate variation in their QS. Moreover, 9 out of 24 (37.5%) water companies had maximum values of QS, in comparison to their peers, i.e., represent the best practice within the group. Based on the BoD methodological approach, these water companies are located on the production frontier and therefore cannot improve their QS in comparison to other water companies.

To rank the 24 water companies evaluated based on their QS, a CI based on the super-efficiency model described inEq. (2) was estimated. The results in Fig. 2 illustrate that the QS ranges between 0.71 and 3.07. As it was expected from a theoretical point of view, the water companies display larger variation when the QS was estimated based on the super-efficiency model. Figure 2 shows that there are two water companies (WC12 and WC3) whose QS stands out above the rest of the water companies evaluated. Both water companies are characterized by a large level of investment compliance, committed in their development plans, and also by a notable investment per customer to improve their QS. Actually, WC12 and WC3 had an annual expenditure of 593,796 CLP/customer (733 USD/customer) and 128,160 CLP/customer (158 USD/customer), respectively.[5] In contrast, WC5, which had the worst QS, did not make any repositions in its water and sewerage networks, in 2017. Moreover, only 25% of the investments were committed in its development plan. These low investments in infrastructure, together with a high percentage of non-revenue water (40%), place WC5 as the one with the lowest QS among the sample of water companies evaluated.

4.2 Factors Affecting Quality of Service

Once the QS of the Chilean water companies analysed was estimated, we explored a set of possible exogenous variables affecting them. Potential exogenous variables were selected considering the features of the water sector and the availability of data (Marques et al. 2014). Hence, the following 6 exogenous variables were investigated: (i) water and sewerage tariff, (ii) water company ownership, (iii) water consumption, (iv) customer density, (v) size of water companies, and (vi) peak factor.

First, an investigation was conducted as to whether the water and sewerage tariff paid by the customers affected the QS provided by the water companies. As reported in Sect. 3.1., in Chile, water and sewerage tariffs are set based on the costs incurred by a simulated efficient water company. It involves notable variations in the charges paid by customers, depending on the water company. Within the group of water companies evaluated, the minimum and maximum water and sewerage tariffs for 2017 were 0.87 and 2.56 US$/m^3, respectively, with an average value of 1.56 US$/m^3. Accordingly, water companies were classified into two groups: (i) tariffs lower than 1.56 US$/m^3, and (ii) tariffs larger than 1.56 US$/m^3. One might expect that where customer charges are higher, water companies should provide better QS because they have more funds to invest. The results in Table 2 show that there is no statistically significant impact on the QS of Chilean water companies, by water and sewerage tariffs paid by customers. This result is consistent with past research, which evidenced the lack of tariff impacts on water services provided by Japanese and Chilean water companies (Marques et al. 2014; Molinos-Senante et al. 2015).

[5] To deal with the presence of outliers, the robust directional BoD model proposed by Vidoli et al. (2015) can be employed.

Table 2 Evaluation of the exogenous variables affecting the QS of Chilean water companies

Exogenous variable	Number of water companies	Mean QS	*p*-value
Water and sewerage tariff (US$/m^3)			
< 1.56	13	0.836	0.569
> 1.56	11	0.922	
Ownership			
Full private	12	0.926	0.034
Concessionary	11	0.944	
Public	1	0.807	
Water consumption (L/customer/day)			
< 211.7	19	0.937	0.046
> 211.7	5	0.894	
Customers density (customer/km)			
< 59.2	13	0.934	1.000
> 59.2	11	0.922	
Size of water companies			
Small	18	0.934	0.803
Medium	4	0.920	
Large	2	0.890	
Peak factor			
< 1.21	17	0.981	0.009
> 1.21	7	0.821	

Water companies in Chile present three types of ownership: full private, concessionary, and public. The results (Table 2) illustrate that private (full private and concessionary) water companies present better QS than the public one. The Kruskal–Wallis test led us to reject the hypothesis of equality of means for the QS index, at a 95% level of significance. This finding shows that the ownership of water companies is an explanatory factor of its QS. Moreover, the QS provided by the concessionary water companies is slightly better than that of full private water companies, since their average CIs were 0.944 and 0.926, respectively.

According to the current sample, Chilean water company customers consume an average of 211.7 L per day. Nevertheless, significant differences are reported among the water companies, which evaluated the minimum and maximum values as 127.2 and 611.5 L/customer/day. In order to investigate whether the water consumed affects the QS provided by the water companies, the sample data was categorized into two groups: (i) water consumption lower than 211.7 L/customer/day and (ii) water consumption higher than 211.7 L/customer/day. Table 2 shows that the customers supplied by 5 water companies consume more than 211.7 L of drinking water per customer, per day. The average QS provided by these water companies is lower than that of the other group of water companies, with statistically significant differences (p-value = 0.046). This finding shows that, in our empirical application, water consumption is an explanatory factor of the QS provided by water companies.

The literature is inconclusive about the impact of customer density on the efficiency of water utilities (Carvalho and Marques 2011, 2016; Guerrini et al. 2018). Hence, it is worth investigating whether this variable affects the QS provided by water companies in Chile. The average customer density, expressed as the number of customers per kilometre of water pipe length, of the water companies evaluated was 59.24 customer/km. According to this value, water companies were categorized into two groups: (i) customer density lower than 59.24 and (ii) customer density larger than 59.24. Table 2 shows that the average QS of both groups of water companies is fairly similar. Moreover, the *p*-value of the Mann–Whitney test is 1.000, which means that the mean QS differences are not statistically significant. In other words, customer density does not affect the QS provided by the Chilean water companies.

The Chilean General Law of Sanitation Services classifies water companies according to their percentage of customers, in relation to total Chilean customers. Hence, to evaluate the possible relationship between the size of water companies and their QS, this classification was employed, as follows: (i) small water companies provide services to lower than 4% of the total national amount of customers, (ii) medium water companies provide services to more than 4% and lower than 15% of the total national amount of customers, and (iii) large water companies provide services to more than 15% of the total national amount of customers. Table 2 illustrates that the 2 large Chilean water companies present, on average, a worse QS than medium and small water companies. However, the Kruskal–Wallis test does not lead us to reject the equality of means hypothesis for the QS index. This finding reveals that the size of the water companies does not impact its QS, from a statistical point of view.

The peak factor is estimated as the ratio between the largest monthly water consumption and the average monthly water consumption across the year (SISS 2017). Within the group of Chilean water companies evaluated, the peak factor ranged between 1.03 and 1.82, with 1.21 the average value for 2017. Based on this average value, water companies were categorized into two groups: (i) peak factor lower than 1.21, and (ii) peak factor larger than 1.21. Table 2 illustrates that most of the water companies (70.8%) present a peak factor lower than the average. This group of water companies, on average, present a better QS than the group of water companies with larger peak factors. One explanation may be that water companies with lower peak factors do not need to make expensive investments to provide water and sewerage services to the seasonal population, and therefore, they have more economic resources available, to improve their QS. Moreover, the *p*-value of the Mann–Whitney test was lower than 0.05 (p-value = 0.009), which allowed us to reject the null hypothesis at the 95% significance level; this implies that peak factor is an explanatory factor of the QS provided by the Chilean water companies assessed.

In summary, the second-stage analysis conducted, has evidenced that ownership and peak factor of the water companies, and the daily water consumed by the customers, affects the QS provided by water companies. These factors are external to water companies since, at least in the short run, their capacity to manage them is limited. Hence, the role of the regulator in improving the QS of the Chilean water companies is fundamental. As the regulatory model adopted in Chile does not integrate the QS provided by water companies in water tariffs, the regulators should introduce direct incentives. The first step should be the identification of key indicators to be improved. For example, Chile is currently suffering the worst drought in its history. All of the rivers of the country have flows that are below their average, and in the centre of the country, the flow of the rivers is below their historical minimum (DGA 2020). Hence, a priority indicator that needs to be improved should be non-revenue water, as it involves both leakages and water thefts. To cope with this extreme drought, all water users should introduce measures to save water and improve water efficiency. In the case of the urban water cycle, this process should be modified by the regulator by adopting policies that incentivize investments in monitoring, repairing, or replacing water networks, in order to reduce leakage.

5 Conclusions

Evaluating and improving the QS provided by water companies is one of the main objectives of water regulators. In doing so, the construction of CIs is very useful as they allow for the integration of several PIs into a single index, providing a holistic and multidimensional assessment of the QS of water companies. In this study, based on BoD DEA methodology, we estimated CIs to evaluate the QS of a sample of Chilean water companies, integrating both desirable and undesirable outputs as QS indicators. Moreover, by computing the Nerlove-Luenberger super-efficiency CI, water companies were ranked based on their QS. Finally, the second-stage analysis conducted, allowed us to explore the possible relationship between six exogenous variables and the QS of the water companies.

The case study conducted, evidenced that, on average, the QS provided by the Chilean water companies is favourable, since the mean CI estimated was 0.93. Nevertheless, the super-efficiency assessment revealed that there are two water companies whose QS stands out above the rest of the water companies evaluated. These two water companies should be established as a benchmark and should be analysed in greater depth by the Chilean water regulator, to define policies that encourage other water companies to improve their QS. Finally, this study concludes that the water and sewerage tariff, customer density, and the size of the water companies does not impact the QS. In contrast, the ownership and peak factor of water companies and water consumption influence the QS of water companies. Thus, the QS provided by the concessionary water companies is the best. Moreover, water companies whose peak factor is lower than the average (1.21) present a larger QS value than the group of water companies with higher peak factors.

The CI computed in this study, to evaluate and rank the QS of water companies, is very useful for water regulators as it allows the integration of both direct and reverse QS indicators. Moreover, it provides a holistic assessment of the QS, that, together with the identification of exogenous variables affecting QS indexes, constitutes a relevant input for water regulators to define policies that incentivize investments that improve the QS. This issue is especially relevant in countries such as Chile, where QS indicators are not integrated in the process of setting water tariffs, i.e., in countries where QS of water companies is regulated following an indirect approach.

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Code availability MaXDEA and GAMS (General Algebraic Modelling Software) software were employed.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Availability of data and material Data will be available upon request.

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