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Technical efficiency in Chile's water and sanitation providers

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ABSTRACT

Chile achieved universal levels of coverage in water, sewerage and wastewater treatment in urban areas. The providers show complete cost recovery, universal metering and diminishing consumption. But investments in Non-Revenue Water control have been deemed insufficient. We explore the sector's comparative technical efficiency, in recent years, and address new challenges related to Non-Revenue Water reduction. We find that a 10 percent reduction in Non-Revenue Water implies a 2.6 percent increase in the input vector. Regulators can induce providers to invest more by recognizing the increased costs, and influence efficiency gains sharing with clients, including automatic coefficients in the rate formula.

1. Introduction

Chile's water and sanitation (W&S) sector has made a significant effort in both investments and institutionalization over the last four decades, attaining universal levels of water and sewerage coverage for the urban population, and nearly universal wastewater treatment levels. The sector achieved a full cost recovery, universal micro-metering and the progressive control of volumes consumed.[1] It represents a very interesting case study regarding the objectives of service universalization, cost recovery, the rationalization of consumption and environmental improvement, occurring together with major changes in the political regime A critical view of the regulatory mechanism used (model or referential company) shows that it does not solve the asymmetry of information in favor of the regulated company. Additionally, the sector's observers have highlighted the relatively low investments in network maintenance, the stagnation in Non-Revenue Water (NRW) control, and the concentration of company ownership in a few groups, who have achieved cost synergies and economies of scale, which have not been transferred to consumers in the form of lower rates.

In this paper we intend firstly to determine the comparative technical efficiency of the providers and its drivers; secondly, to analyze the evolution of technical efficiency over time, exploring the possibility of transferring efficiency gains to consumers (through an X-Factor); and thirdly to determine a possible path to increase maintenance investments with the aim of reducing NRW (through a K-Factor).

Based on a sample of 18 Chilean providers of water and sewerage for the period 2005–13, we computed an input distance function through a stochastic frontier analysis (SFA). We performed a True Random Effects (TRE) model to control for possible unobserved heterogeneity between providers. We use the results to measure the phenomena under study, and to give support to policy suggestions.

In so doing, we have organized the paper in seven sections. After this Introduction, Section 2 reviews the literature and establishes some facts about the sector's history and evolution. Section 3 discusses the method of analysis and the model to be estimated. Section 4 presents our database. Section 5 discusses the results. Section 6 presents some policy considerations and Section 7 concludes.

2. Evolution of the Chilean water and sanitation sector

2.1. A recent history of the Chilean water and sanitation sector

In 1931 the General Directorate of Drinking Water and Sewerage in the Ministry of the Interior was created to promote the

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[1] Coverage went from 77% to 99% in water, from 43% to 96% in sanitation and from 0% to 100% in sewerage treatment, comparing the years 1975 and 2013 (Alé Yarad, 2013). Cost recovering with tariffs went from 10% in 1973 to 100% in 2000 (Gómez-Lobo, 2001). Between 2000 and 2012, the sector invested on average US$ 270 million per year (Espinosa Sarría, 2014; Ebensperger, 2012).

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institutional development of the country's sanitation sector (Salazar, 2000). In 1953 the Directorate of Waterworks (DOS) was established to carry out the study, planning, construction, repair, administration and provision of facilities for potable water and sewerage, implying a partial unification of the supervision of the sector (Ebensperger, 2012). The DOS joined the Department of Hydraulics of the Ministry of Public Works and the Directorate General of Drinking Water of the Ministry of the Interior (Salazar, 2000). In 1973, 74 percent of the financing came from fiscal resources, 16 percent was external and only the remaining 10 percent was derived from rates. Most of the spending targeted investments to expand coverage, whereas expenditure on maintenance fell below 15 percent. Between 1968 and 1973, the personnel increased from 3800 to 13,500 (Fischer and Serra, 2007).

In 1977 SENDOS[2] was created as the single state agency (rural and urban) for the operation and maintenance of sanitation systems, also acting as the regulatory and supervisory body under the Ministry of Public Works. The State funded investments and there was a system of tariffs based on cross-subsidization between regions without considering the costs of providing the service. This system operated centrally in the area of investment planning, resource allocation and pricing, the regional SENDOS providing only operational services (Sistema de Empresas, 2006). Its headquarters operated in 11 of the 13 regions and there were two autonomous state-owned companies in the remaining regions: EMOS[3] (today Aguas Andinas, in the Metropolitan Region) and Esval (in the Valparaiso Region), all under the Ministry of Public Works (Ebensperger, 2012; Sistema de Empresas, 2006; Alfaro, 2009). By 1979 SENDOS's personnel had been reduced to approximately 3000 employees (Fischer and Serra, 2007).

In 1988 a law for Sanitation Services (Decree with the force of Law 382) was passed, giving autonomy to the providers. With this, the two regional companies became subsidiaries of CORFO,[4] which is the governmental agency for economic and industrial development, acting as a holding company of public enterprises (Fischer and Serra, 2007). They also began to implement efficient rates and self-financing criteria. The Law sets the rules for the operation of the sanitation providers, the conditions in which they must provide the services and the regime of concessions that they operate, Supreme Decree 121 in 1992 (Alegría Calvo and Celedón Cariola, 2006).

In 1989 the new institutional framework for the sector was established with the separation of the roles of producer (in charge of the companies) and regulators (in charge of the SISS[5]). The SISS was created by Law 18,902 in 1990 (Gómez-Lobo, 2001) and constituted an essentially technical, regulatory and supervisory body (Alegría Calvo and Celedón Cariola, 2006). In 1998 the SISS was granted greater authority and a higher budget (Espinosa Sarría, 2014). The SISS is responsible for setting rates, conducting studies and overseeing the sector. The SISS is intended to be autonomous of the political power, although its chairman is appointed and can be removed at any time by the president, and its budget is voted by the congress. Hierarchically, the Superintendent depends on the Ministry of Public Works. Funding comes from the national budget (Gómez-Lobo, 2001). The Decree with the force of Law 70 of the Ministry of Public Works (General Law on Rates) sets down the procedures and standards to determine tariffs (Alegría Calvo and Celedón Cariola, 2006). Until January 1990, the Ministry of Economy determined the tariffs, which then fell under the responsibility of the SISS. Law 18,778 in 1989 established a direct subsidy for consumption, awarded by the State through the municipalities, allowing the tariffs to reflect private supply costs. In practice, the subsidy covers discounts on the invoice for 15 percent of the users.

In the 1990s EMOS (today Aguas Andinas), Essbio, Essal and Esval were privatized, although the State retained a minority stake in the property. In the mid-1990s the former SENDOS regional companies were transformed into eleven corporations, all subsidiaries of CORFO (Sistema de Empresas, 2006). Initially, three state-owned companies sold strategic participations to private consortia with experience in the water industry. After that, from 1998 to 2000, a significant part of the capital of the main Chilean water and sanitation providers was privatized. In 2001, the Chilean Government decided to transfer to the private sector, for a fixed term, the remaining companies (Molinos-Senante et al., 2015). In 2011, the State sold the shares it held in all of the privatized enterprises, except for a 5-percent participation in the hands of CORFO, allowing it to choose a director and wield veto rights for some decisions (Golden Share). In 1998 Law 19,549 amended the legislation and regulatory framework of the sector, introducing limits on the ownership structure to prevent an excessive concentration in the sector both at the horizontal and sectoral levels (Gómez-Lobo, 2001).

Privatization was motivated by the need to count with private financing for investment projects in wastewater treatment. In 1995, and owing to the country's decision to open up to the world economy through free trade agreements, which demanded health and environmental obligations that Chile did not meet in export products, a policy priority was given to wastewater treatment (Alegría Calvo and Celedón Cariola, 2006). For its part, the change in the privatization model – moving away from perpetual concessions to 30-year agreements, opening 10 percent of the capital in the stock market and up to 10 percent of the shares for purchase by the employees – was partly influenced by the view that the regulatory framework was still too precarious to regulate these companies successfully (Gómez-Lobo and Vargas, 2002). The privatizations implied the collection of US$ 2500 million and between 2000 and 2012 the industry invested US$ 3561 million in various infrastructure works, mainly for wastewater treatment (Espinosa Sarría, 2014; Ebensperger, 2012).

Table 1 shows the evolution of the water coverage that 50 years before had reached just half of the population and of sewerage coverage that had reached only a quarter. It is currently universal in both services. In addition, the universalization of wastewater treatment was achieved.

Rural providers covering 11 percent of the population are organized into cooperatives and do not require concessions granted by the SISS, while urban areas are covered by concessions granted

Table 1
Coverage evolution (in percent of the population).

Year	Drinking water	Sewerage	Wastewater treatment
1965	53.5	25.4	0
1970	66.5	31.1	0
1975	77.4	43.5	0
1980	91.4	67.4	0
1985	95.2	75.1	0
1990	97.4	81.8	8.0
1995	98.6	89.4	14.0
2000	99.6	93.1	20.9
2013	99.8	96.1	100.0

(Source: Alé Yarad, 2013.)

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[2] Servicio Nacional de Obras Sanitarias (National Service of Water Works).

[3] Empresa Metropolitana de Obras Sanitarias (Metropolitan Water Works Company).

[4] Corporación de Fomento de la Producción (Corporation for Production Development).

[5] Superintendencia de Servicios Sanitarios (Sanitation Services Superintendency).

by the SISS (plus the single municipal services state-owned provider SMAPA), which altogether comprise 89 percent of the population.

Before the reform, tariffs managed to recover less than 50 percent on average of the operating costs and in some water source-poor regions (in the north of the country), the cost coverage was lower than 20 percent (Serra, 2000 cited by Gómez-Lobo, 2001). The increase in tariffs recorded during the 1990s made it possible to reverse the financial deficit of the providers. At the same time, the increase reduced the average consumption per customer and production by the companies. The NRW, however, have increased in time, which indicates a probable lack of investments in networks maintenance (Alegría Calvo and Celedón Cariola, 2006). An indicative measure of the intensity of investment in infrastructure maintenance can be expressed by the number of years it will take to renew the entire network. Likewise, the sector currently operates with half of the personnel employed at the beginning of the reform process. Some staff is outsourced (Alegría Calvo and Celedón Cariola, 2006).

Prior to the reform process, price discrimination between regions was common (10 percent of each regional SENDOS revenue was redistributed to poor regions) and by volumes consumed (in growing blocks of less than 15 cubic meters per month, 15–45, and more than 45) (Sjöden, , 2006). The current pricing system does not distinguish between the socio-economic situation of the customers: the tariffs are fixed per cubic meter consumed according to “efficient production costs” and apply to all customers equally. No distinction is made between residential, commercial or industrial customers (but there are seasonal and “overconsumption” rates). Since 1990 subsidies have been designated for poor families, who must apply to qualify. They receive the subsidy as a variable discount in their invoices, according to the grade obtained in the means testing of the Social Protection Survey (Espinosa Sarría, 2014 and SISS website).

2.2. *Brief review of the literature on the Chilean water and sanitation reform*

Chile is a middle income country that has implemented significant reforms to improve W and S sector, according Hearne and Donoso (2005) who study the institutional reforms in the sector. The case of water industry in Chile provides an example of full privatization in a monopoly sector that has achieved near universal access in urban areas (Baer, 2014). A full recovery costs policy was introduced in the early 1990s, generating important rate growth (Molinos-Senante and Sala-Garrido, 2015). As this authors highlight, the Chilean Government, through the SISS, implemented two main approaches for the privatization of the water industry in Chile. Initially, shares of three operators were sold, their capital was made public through the stock market and the state reserves golden shares. A second wave of privatizations granted concessions for a fixed time, seeking to remedy the utilities' inefficient allocation of resources and to improve quality of services (Frade and Sohail, 2003).

Tariffs are set for a period of five years, and can be indexed within the tariff period when a cost index exceeds an accumulated 3 percent. Both the authority and the company may then deem it necessary to adjust tariffs if an extraordinary event during the review period proves it necessary. Tariffs are maximum prices: companies may charge lower values. Determining the new value is based on technical support using a regulator's report, another by the company and the differences are settled by a committee of experts who must elect one of the two studies for each of the points where discrepancies lie. The cost studies use a model, or referential company (fictitious), designed to provide services efficiently (Gómez-Lobo, 2001; Marques et al., 2011). Based on the estimation of the long-term costs of this hypothetical efficient firm, the regulator and the provider propose the water tariff. If there is no agreement, an arbitration process settles differences between parties. Tariffs are differentiated by stage and between fixed and variable charges, including a component for the months of peak demand (summer). Prices are calculated on the basis of the incremental costs of development (marginal long-term costs). Efficiency tariffs are adjusted by the percentage needed to reach the required revenue. Charging is calculated by system and not by company. The mechanism of the model company has been criticized because the costs of the real company are not considered to determine rates. Tariffs unrelated to costs could force the regulator to micromanage the company, prevent the use of incentives and yield practical problems that can distort the rates process (Gómez-Lobo and Vargas, 2002).

3. Methodology

Following Worthington (2013), there are basically two approaches for efficiency frontier estimation: nonparametric (mathematical programming approach), and parametric (econometric approach).

The econometric approach (namely, SFA, when panel data are involved) specifies a production, cost or profit function and recognizes that deviation from the estimated function (as measured by the error term) is composed of two parts,[6] one representing randomness (or statistical noise) and the other inefficiency.

The mathematical programming approach most commonly employed is “data envelopment analysis” (DEA). DEA essentially calculates the economic efficiency of a given utility relative to the performance of other utilities producing the same sorts of services. DEA is non-stochastic method in that it assumes all deviations from the frontier are the result of inefficiency.

Molinos-Senante and Sala-Garrido (2015) and Molinos-Senante et al. (2015) have made use of the DEA approach in two recent papers concerning Chilean water sector. So our SFA approach could fill a gap in the literature. Each family of approaches has relative advantages with respect to the other. Parametric methods allow testing hypothesis by means of statistic tests, while non-parametric ones permit to detect outliers in the sample. In that sense, methods can be conceived more as complements than as substitutes.

The philosophy of frontier efficiency analysis is different from the efficiency concept which permeates in the model company. In the latter, the concept of efficiency which is used to compare the performance of the real company is an ideal or theoretical level, while in the econometric or DEA frontier analysis the efficiency levels are real life best practices. Then, the model company efficiency concept is an absolute, while the frontier analysis is a relative concept (Correia and Marques, 2011).

In the primal (production) form of the SFA, we specify an output as a function of inputs. Unfortunately, it is difficult to incorporate multiple outputs in this form, though it is possible with the dual function (cost frontier). Accordingly, the stochastic frontiers typically used in water utilities efficiency analysis are cost frontiers, where costs are regressed against outputs and input.

Given that we have no price information we are not able to build a cost frontier, so we can only work with the production function. But provided we have more than an output and we are not able to express them as a function of inputs or distinguish what fraction of an input x_j is assign to output y_i or reasonably aggregate them. That

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[6] Ordinary Least Squares does not make this separation. In this sense, is a “deterministic” method, while SFA is “stochastic”.

is why we use distance functions to estimate the characteristics of a multiple-output production technology. An input distance function characterizes the production technology by looking at a minimal proportional contraction of the output vector. It allows us to describe a multi-input, multi-output production technology without the need to specify a behavioral objective (such as cost-minimization or profit maximization). The model used in this paper is drawn from Coelli et al. (2005) and follows Saal et al. (2007) research strategy.

The production technology can be fully described by the input distance function, which yields the maximum deflation factor that must be applied to an observed input bundle x (a vector of N dimensions) in order to project it onto the efficiency frontier of the input requirements set ($I^t(y)$). Thus, for the output vector y (a vector of M dimensions) at time t (see Panel (a) in Diagram 1):

$$D_I(y,x,t) = \max\left\{\delta : \frac{x}{\delta} \in I^t(y),\ \delta > 0\right\} \tag{1}$$

It therefore follows that technically inefficient components of $I^t(y)$ will have $D_I(y,x,t) > 1$, while technically efficient allocations will have $D_I(y,x,t) = 1$. Similarly, it follows that $D_I(y,x,t) = (1/TE_I^{it}) \geq 1$, where TE_I^{it} is a Farrell measure of input based technical efficiency, and $\ln D_I \geq 0$ is the technical inefficiency of the firm.

The choice of an input distance function rather than an output distance function is driven by the nature of production and regulation in Chile's water and sewerage industry. Measuring efficiency with an alternative output distance function implies adopting an output–oriented approach in which efficiency is improved by increasing outputs given an exogenous input allocation. In contrast, measuring efficiency with an input distance function implies adopting an input-oriented approach in which efficiency is improved by reducing input usage for a given exogenous output level. Considering that providers have a statutory obligation to meet demand, we can assume that outputs are exogenous while inputs are endogenous, rather than the reverse. Important properties of the function $D_I(y,x,t)$ are that it is non-decreasing, linearly homogeneous and concave in inputs, non-increasing and quasi-concave in outputs.

We choose a functional form that expresses the log-distance as a linear function of (transformations of) inputs and outputs. Although the Translogarithmic is more flexible to accommodate for an unknown technology, we choose the Cobb-Douglas functional form because the sample is very small and the former option would consume many degrees of freedom.

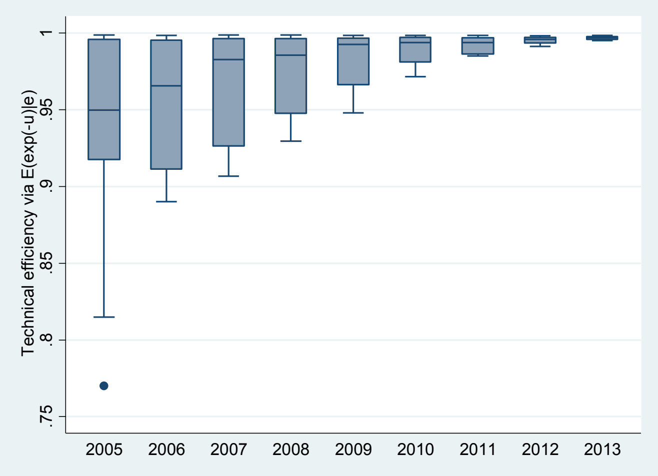

Fig. 1. Technical efficiency scores: Catch-up process.

The function then becomes:

$$\ln D_{it}(y,x,t) = \alpha + \sum_{n=1}^{N} \beta_n \ln x_{nt} + \sum_{m=1}^{M} \gamma_m \ln y_{mt} + \tau t + v_{it} \tag{2}$$

Where $v_{it} \sim N(0, \sigma_{vi}^2)$ is a random error, introduced to account for approximation errors and other sources of statistical noise, and τ is the periodic contraction (or expansion) in the input vector.

This function is non-decreasing, linearly homogeneous and concave in inputs if $\beta_n \geq 0$ for all n and if:

$$\sum_{n=1}^{N} \beta_n = 1 \tag{3}$$

We impose homogeneity of degree 1 in inputs by deflating all but one of the inputs by the remaining input and then re-arrange it so that the negative of said input is the dependent variable in the regression.

$$\begin{aligned} -\ln x_{Nit} = {} & (\alpha + w_i) + \sum_{n \neq N} \beta_n \ln\tilde{x}_{nit} + \sum_{m=1}^{M} \gamma_m \ln y_{mt} \\ & + \sum_{m=1}^{M} \theta_k \ln z_{kit} + \tau t + v_{it} - u_{it} \end{aligned} \tag{4}$$

where $\tilde{x}_{nit} \equiv (x_{nit}/x_{Nit})$, $u_{it} = \ln D_{it}(y,x,t)$ is a non-negative variable associated with technical inefficiency, and has the following half-normal distribution $u_{it} \sim N^{+}(0, \sigma_{ui}^2)$. In addition, u_i and v_{it} are independently distributed from each other and from the model's covariates. Following standard practice (Saal and Parker, 2005), the technical efficiency of firm i at time t can be modelled as $TE_I^{it} = e^{-u_{it}}$.

The modeled function differs from the standard Cobb-Douglas approximation to the input distance in three important aspects.

First, it is enhanced by the addition of a vector z exogenous operating characteristics of k dimension, whose impact on input requirements is captured in the term θ_k. Panel (b) in Diagram 1 presents the contraction in the input vector associated to two different exogenous operating characteristics. For the same vector of inputs and outputs observed the relevant frontier is conditional on the context. For positive values, a shift in the context variable from (z_0) to (z_1) implies that for the same vector of inputs and outputs the distance to the efficient frontier is greater. Alternatively, for the same output vector, the input vector required to produce (z_1) is smaller than in (z_0).

Second, in order to account for possible unobserved heterogeneity we introduce w_i which is a firm-specific effect, obtained through the True Random Effect (TRE) method developed in Greene (2005). These random effects allow us to control for further factors influencing input requirements that have not been specifically controlled for in the model.

Third, following Caudill and Ford (1993), Caudill et al. (1995) and Hadri (1999), we parametrize the variance of the pre-truncated inefficiency distribution in the following way:

$$u_i \sim N^{+}\left(0, \sigma_{u_i}^2\right) \tag{5}$$

$$\sigma_{u_i}^2 = \exp(h_i'\varphi) \tag{6}$$

where h_i is a variables vector related to the firm (including the intercept) and φ is a vector of unknown parameters. Caudill and Ford (1993) find that heteroscedasticity leads to an overestimation of the intercept and an underestimation of the slope coefficients.

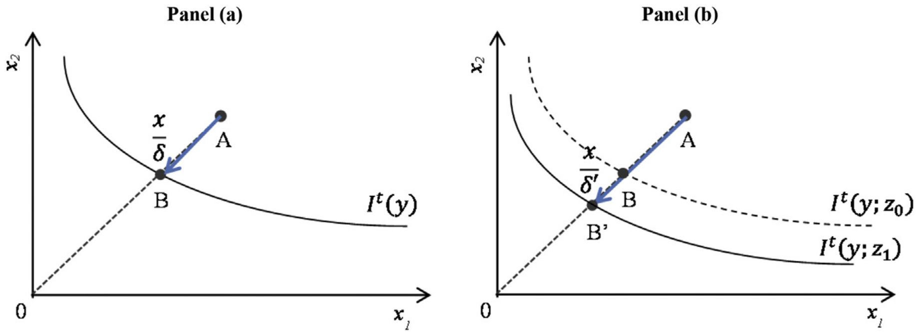

Diagram 1. Input distance function: Two inputs and a single output.

We also extend the model by allowing the variance of the idiosyncratic error to be heteroscedastic. If we assumed the contrary, it would bias the efficiency estimates:

$$v_i \sim N\left(0, \sigma_{v_i}^2\right) \tag{7}$$

$$\sigma_{v_i}^2 = \exp(g_i' \rho) \tag{8}$$

Although our TRE model may appear to be the most flexible and parsimonious choice among the several existing time varying specifications, we can argue that a portion of the time-invariant unobserved heterogeneity does belong to inefficiency or that these two components should not be disentangled at all. We employ a balanced panel of 18 providers with 9 years of data (2005–13). Therefore, given our long panel data, it is difficult to argue that the random effects capture an estimated time invariant level of inefficiency. If this were the case, then our study would constitute a lower bound of inefficiency.

We acknowledge that by using TRE we were not allowing for a correlation between w_i and the regressors. This problem could be solved estimating True Fixed Effects (TFE) or through Mundlak's (1978) correction. However, if some of the explanatory variables have a very low degree of within-group variability, the parameter vector is not estimated precisely at all: this is what happens in our model, where the network related variables show minor variability. For this reason, we have decided to leave aside TFE and estimate a TRE model, which is less reliant on the within variability of the regressors. The TRE model assumes a zero correlation between w_i and the regressors. Due to our small sample, Mundlak's (1978) correction was very difficult to implement because it consumed many degrees of freedom.

We therefore follow Greene (2005) and employ simulated maximum likelihood techniques to allow for firm-specific random effects, while also allowing for a time-varying inefficiency specification. The unknown parameters to be estimated are α,β_n,γ_m, θ_k, τ, as well as the variance terms of the composed error idiosyncratic and inefficiency components σ_v^2, σ_{ui}^2 and φ. For estimation purposes, the last three parameters are not directly estimated, but, instead, the model is estimated using the re-parameterization $E(\sigma) = E\left[\left(\sigma_v^2 + \sigma_{ui}^2\right)^{1/2}\right]$, which is the standard deviation of the overall error variance, and $\lambda = \sigma_{ui}^2/\sigma_v^2$, which has the advantage of being a useful indicator of the relative importance of inefficiency in the overall error variance.

4. Data

We built a sample of 162 observation coming from a balanced panel of 18 Chilean providers of water and sewerage for the period 2005–13. All data was extracted from the SISS annual reports available on the regulator web page[7]

To implement Equation (4) we choose to model companies, which are integrated water and sewerage utilities, as multiple output producers of water and wastewater services measured with the number of water clients (y_{client}) and water supply expressed in thousands of cubic meters of annual water produced (y_{water}), The same strategy is used by Saal and Parker (2005) because Garcia and Thomas (2001) and Stone and Webster Consultants (2004), have emphasized that significant modelling improvements result if both the physical volume of water output as well the number of water connections are modelled as outputs. We did not consider wastewater collection or wastewater connections because they are highly correlated with water production and water connections, respectively.

We assume there are two inputs: personnel ($x_{personnel}$) which is the sum of firm's personnel and full time equivalent outsourced personnel and total network ($x_{network}$) which is the sum of the water and the sewerage networks in kilometers. We use $x_{network}$ as a numeraire to impose the homogeneity condition.

Technical change is captured by the time trend (t) and we enhance the model by the addition of the following operating characteristics: NRW (z_{nrw}) measured as one minus the ratio of billed to produced water, Return on Assets (z_{ROA}) and level of investments (z_{Inve}) measured in “Unidades de Fomento” (UF) which is a widely-used Chilean Consumer Price Index (CPI) indexed unit (In use since the 1960s, to avoid distributive consequences of high inflation in contracts, it adjust nominal pesos by the CPI of the previous month. See Appendix). NRW was included to allow for the fact that water utilities cannot produce and sell water to final customers (a desirable output) without losing part of the production (an undesirable output). Garcia and Thomas (2001), Martins et al. (2008), and Corton (2011) also employ volumes of water delivered and water losses as outputs in their analysis of the water industry in Portugal and Peru, respectively. The Return on Assets was included to account for the possibility that less assets would imply the need for more input factors to produce the same output and the level of investment was included because we cannot distinguish what is the share of capital or labor devoted to investment or operational activities. So we would expect that during the investments process to see more inputs for the same output.

Finally, in Equation (6) the vector h_i' that accounts for heteroscedasticity in the inefficiency component, is represented by the time trend (t) and the constant, while in Equation (8) the vector g_i' that accounts for heteroscedasticity in the variance of the idiosyncratic error $\sigma_{v_i}^2$ is composed by time trend (t), the constant and

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[7] www.siss.cl/577/w3-propertyvalue-3443.html.

Table 2
Descriptive Statistics of the variables in the estimates.

Variable	Definition	Type	Unit	Obs	Mean	Std. Dev.	Min	Max
y_{client}	Water clients	Output	Number	162	240,949	362,909	3059	1,725,516
y_{water}	Water production	Output	000 m3	162	84,238	135,290	1565	626,589
$x_{network}$	Total network	Input	Km	162	3723	4965	89	21,356
$x_{personnel}$	Total personnel	Input	Number	162	647	723	50	3014
z_{nrw}	Non-Revenue Water	Context	%	162	0.323	0.116	0.064	0.554
z_{ROA}	Return on Assets	Context	%	162	0.093	0.046	(0.037)	0.224
z_{Inve}	Investments	Context	UF[a]	162	432	732	(1267)	5637
g_{Cons}	Average consumption	Context	m3 per client/month	162	25.0	23.3	13.1	124.8

[a] For the value of the UF (Unidad de Fomento, indexed unit) in every year see Table in Appendix.
(Source: Author's Own Elaboration on SISS data.)

the mean consumption by client (g_{Cons}) measured as the ratio of billed water to clients. This last variable seeks to capture differences that come from the type of users (Non-residential clients consume more water on average).

Table 2 presents the descriptive statistics of the variables used in the estimates. Our sample is a balanced panel with 162 observations over the years 2005–2013 for 18 companies. There are other minor providers that began to operate in very recent years. We decided not to include the latter for the sake of balancing the sample, also taking into account the low importance of the new providers with respect to the size of the market.

5. Empirical results and discussion

We computed the input distance function presented in Equations (4) to (8) through a stochastic frontier analysis (SFA), performing True Random Effects to control for possible unobserved heterogeneity between providers. The estimated model is presented in Table 3.

We first consider β_{PERS}, and β_{NETT} (coefficients for our proxies to labor and capital, respectively). The parameters reveal that the providers' distance function input elasticities for personnel and network are 0.043 and 0.957, respectively,[8] thereby accurately reflecting the relative input contribution shares of a capital intensive industry.

Focusing then on the output elasticities, Table 3 indicates that γ_{CLIE} and γ_{WATE} are negative and significantly different from zero, implying that the estimated distance function is decreasing in outputs. Thus, the model is well specified: increases in output vector shorten the distance function. The estimated returns to scale for the sample are $1.081 = 1/(0.8 + 0.12)$, statistically different from one, therefore suggesting that the industry is characterized by increasing returns to scale. Nevertheless, we suggest caution in the interpretation of these results, because the Cobb-Douglas specification assumes that returns to scale are the same for the sample as a whole. Then, we can only assess that in the neighborhood of average values there are economies of scale. These results contrast with Molinos-Senante et al. (2015) who find that Chilean water companies exhibit constant returns to scale using DEA method, while SCL Econometrics (2009) finds economies of scale in the stages of production of water, sewerage recollection, treatment and administration, and neither economies or diseconomies of scale in water distribution. These differences show that results are sensitive to the method employed, and require further research to reconcile them. Saal et al. (2007) and Ferro et al. (2011) provide detailed surveys of scale economies analysis in the sector around the world, and Carvalho et al. (2012) go beyond, with a meta regression study. The evidence on economies of scale and scope in the sector is mixed around the world. The coefficient associated with the time trend τ is statistically not significant and suggests that there was no technical change in the period under analysis throughout the sample. The lack of technological change during this period might be explained by improved environmental impacts (related to better hydrological stewardship and reduced effluent or pollution) which were not included in the model.[9] This coefficient is relatively low in the sector, indeed Saal et al. (2007) find a technical change of 1.8 percent for the period 1986–2000 in England and Wales and Saal and Parker (2005) find an estimate of 2.4 percent at the average sample but declining by 0.5 percent per year.

The NRW coefficient θ_{NRW} is positive and statistically significant: increases in NRW lead to decreased input requirements. Its value suggests that costs associated with water loss detections, repairs and controls are more substantial than the costs of producing and distributing additional cubic meters of water. Reduction in 10 percent of NRW implies an increase of 2.6 percent in the input vector. This result is consistent with Garcia and Thomas (2001).

The Return On Assets coefficient θ_{ROA} is positive and statistically significant: increases in the ROA decreases input requirements. In other words, providers less capital intensive, in order to reach the efficient frontier, have to make a larger contraction in the input vector. We acknowledge being cautious with this result because we could have reverse causality: less input usage implies higher return on assets.[10]

Although the Investments coefficient θ_{INVE} has a very low value, it is positive and statistically significant, implying that increases in the level of investments would lead to decreasing input requirements. Specifically, if the investments were doubled, the input requirement would shrink by 1 percent. This result suggests that there is a trade-off between the investment and input requirement.

With regard to the idiosyncratic error, we posed two arguments: first, the time trend (t) and, second, the average consumption per client ($\ln g_{Cons}$). A negative coefficient ρ_t would imply that throughout the years, firms have become similar, but the time trend resulted statistically not significant so we cannot claim that providers became more similar. Average consumption attempts to capture the effect of larger clients. We hypothesized that greater average consumption implies ceteris paribus a greater share of industrial clients. The positive sign and statistical significance of ρ_{consum} imply that increases in average consumption per client make providers less similar because they may require different input mixes. Providing water to industrial clients has to affect input usage and both go in opposite directions. On the one hand, it reduces input requirements because less commercial effort is needed (metering, billing, claims) for the same output delivered. This result

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[8] Since NETT has been used as a numeraire, the NETT elasticity can be recovered as βNETT = 1-βPERS.

[9] We thank an anonymous referee for this interpretation.

[10] We thank an anonymous referee for this point.

Table 3
Results.

Variable	Label	Parameter	Coefficient	Standard error
Frontier				
$x_{personnel}$	Personnel	β_{PERS}	0.043^{***}	(0.014)
y_{clien}	Clients	γ_{CLIE}	-0.801^{***}	(0.021)
y_{water}	Water production in 000 m3 per month	γ_{WATE}	-0.124^{***}	(0.022)
T	Trend	τ	0.000	(0.002)
Z_{nrw}	Non-Revenue Water	θ_{NRW}	0.257^{***}	(0.059)
z_{ROA}	ROA	θ_{ROA}	0.198^{**}	(0.086)
z_{Inve}	Investments	θ_{INVE}	0.008^{**}	(0.004)
Constant	Constant	α	-0.212^{***}	(0.024)
Usigma				
h_t	Trend	φ_t	-0.696^{**}	(0.349)
$h_{constant}$	Constant	$\varphi_{constant}$	-8.118^{***}	(1.243)
Vsigma				
g_{Cons}	Average consumption	ρ_{consum}	1.737^{***}	(0.298)
g_t	Trend	ρ_t	0.075	(0.215)
Constant	Constant	$\rho_{constant}$	-6.965^{***}	(0.267)
Theta				
Constant	Constant		0.165^{***}	(0.005)
Observations			157	
Number of firms			18	

Standard errors between parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

is also found in Mizutani and Urakami (2001). On the other hand, a larger share of industrial clients might have a significant influence on wastewater treatment input requirements. Saal et al. (2007) find that relatively greater industrial effluent treatment results in higher input requirements. Given that the idiosyncratic error was heteroscedastic, if we had assumed homoscedasticity, then the inefficiency estimate would have been biased in favor of those providers with fewer industrial clients.

Although the time trend did not explain the idiosyncratic error ρ_t, coefficient h_t is a very important argument to explain the inefficiency dispersion, been φ_t negative and statistically significant. It means that over time, there has been a catch-up process as can be seen from the Technical Efficiency Scores of depict in Fig. 1. Providers with lower efficiency rates improved their technical efficiency at a greater pace. In the case of Brazil Ferro et al. (2014) find a catch up process for the years 2003–2010. In order to make this point clearer, Table 4 provides the resulting Technical Efficiency Scores for each company for every year. The outer rows and columns account for average and standard deviations for years and providers, respectively. The last rows show that in 2005 technical efficiency was 94.1 percent with a standard deviation of 6.5 percent and a minimum of 77 percent, while in 2013 those numbers were 99.7 percent, 0.01 percent and 99.5 percent, respectively. Saal et al. (2007) also find very high technical efficiency scores in England and Wales (around 95 percent), but instead of a catch-up process they find that average and median efficiency peaked 96.4 percent in 1990, and then declined after privatization to 94.9 percent in 2000. Saal and Parker (2005) distinguish between Water-Only Companies (WoC) and Water and Sanitation Companies (WaSC) in England and Wales, and find for both cases that efficiency scores are around 95 percent but the WoC frontier suggests a period of improvement in average WoC efficiency until 1996, followed by a period of largely sustained and stable weighted average efficiency estimates, while the pattern of WasC frontier suggests that average efficiency declined until 1996, then improved in a possible response to regulatory pressure resulting from the 1994 price review, before declining again until 2000, when another improvement, possibly in response to the 1999 price review, occurred.

As it can be appreciated, basically all firms converged to the frontier. This can be explained by inclusion of factors beyond managerial control (density).[11]

6. Policy considerations

If we compare the Model Company with the traditional Price Cap scheme (i.e., RPI-X), the differences are as follows:

Under RPI-X: P1 = P0 (as determined in the periodical tariff review) * (1 + CPI-X)

In Chile: P1’ = P0' (as determined on the basis of the “Model Company”) * (1 + Cost Index if > 3 percent accumulated).

The Chilean sector reform has met important goals in coverage (both drinking water and sewerage) and sewerage treatment. It has been criticized because tariffs have not decreased sufficiently over time and maintenance investments have not sufficed to reduce NRW. Both assertions need clarification.

First, regarding tariffs, we have prepared an index which explains tariff variations. First, we collected data on the 20 cubic meters of a monthly invoice (that is, approximately, the average consumption per client starting from 23 at the beginning of the period to almost 19 nowadays). Since almost every operator presents different prices for two or more places, we selected the largest city of each operator as representative (see the chosen localities in the Appendix). We then calculated the mean 20 cubic meter invoice in UF. Its cost was 0.93 in 2005, on average, and dropped to 0.84 in 2013. There are two additional considerations: one, there is a strong standard deviation since potable water is very expensive in some parts of the country (especially in the highly arid northern region and some areas in the south); and two, we do not weight per number of clients since the Metropolitan region accounts for one-third of the total population. From the data, we took 2005 as the base year and then determined a decreasing index in real terms in the last three years of the series. Comparing 2005–2013, our index of tariffs decreases by 10 percent in real terms.

Second, we calculated the mean NRW. On average it was 33 percent in 2005, decreasing to 31 percent in 2013. Again, there is high dispersion between operators and years, as Table 5 shows. The

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[11] We thank an anonymous referee who highlighted this issue.

Table 4
Technical Efficiency Scores for each company for every year.

Firm	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean	Std dev
Altiplano	0.997	0.997	0.997	0.997	0.998	0.998	0.998	0.998	0.998	**0.998**	**0.001**
Andinas	0.994	0.994	0.995	0.995	0.995	0.996	0.997	0.997	0.998	**0.996**	**0.001**
Antofagasta	0.996	0.995	0.996	0.996	0.996	0.996	0.997	0.997	0.998	**0.996**	**0.001**
Araucania	0.942	0.952	0.960	0.979	0.988	0.993	0.994	0.996	0.997	**0.978**	**0.021**
Aysen	0.770	0.903	0.916	0.929	N/A	N/A	0.985	N/A	N/A	**0.901**	**0.079**
Chacabuco	0.999	0.999	0.999	0.999	0.998	0.998	0.998	0.998	0.998	**0.998**	**0.001**
Chanar	0.931	0.962	0.997	0.997	0.997	0.997	0.994	0.996	0.997	**0.985**	**0.023**
Coopagua	0.927	0.932	0.926	0.948	0.966	0.981	0.989	0.993	0.996	**0.962**	**0.029**
Cordillera	0.958	0.969	0.977	0.992	0.994	0.995	0.996	0.997	0.997	**0.986**	**0.014**
Decima	0.993	0.993	0.991	0.991	0.992	0.991	0.994	0.996	0.997	**0.993**	**0.002**
DelValle	0.929	0.893	0.907	0.930	0.948	0.971	0.986	0.993	0.996	**0.950**	**0.038**
Essal	0.900	0.911	0.918	0.945	0.948	0.971	0.986	0.991	0.995	**0.952**	**0.036**
Essbio	0.917	0.935	0.949	0.949	0.966	N/A	0.986	0.993	0.996	**0.961**	**0.029**
Esval	0.998	0.997	0.996	0.996	0.997	0.997	0.997	0.997	0.998	**0.997**	**0.001**
Magallanes	0.914	0.902	0.920	0.935	0.954	0.973	0.986	0.993	0.995	**0.953**	**0.036**
Manquehue	0.815	0.890	0.943	0.967	0.981	0.988	0.992	0.995	0.996	**0.952**	**0.062**
NuevoSur	0.960	0.980	0.988	0.960	0.981	0.982	0.988	0.994	0.996	**0.981**	**0.013**
Smapa	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	0.998	**0.998**	**0.000**
Mean	**0.941**	**0.956**	**0.965**	**0.972**	**0.982**	**0.989**	**0.992**	**0.995**	**0.997**		
Std Dev	**0.065**	**0.041**	**0.035**	**0.027**	**0.018**	**0.010**	**0.005**	**0.002**	**0.001**		
Min	**0.770**	**0.890**	**0.907**	**0.929**	**0.948**	**0.971**	**0.985**	**0.991**	**0.995**		
Max	**0.999**	**0.999**	**0.999**	**0.999**	**0.998**	**0.998**	**0.998**	**0.998**	**0.998**		

Note: N/A reported missing in Stata.

average, since it is a simple arithmetic mean, is highly influenced by two observations of small companies (Coopagua and Manquehue) which report very low NRW levels. To establish the maximum water and sewerage tariff for each company, the SISS assumes percentages of NRW of 15 and 5 percent in the distribution and production stages, respectively. Additionally, we developed an index to express investments meaningfully and thus to be able to compare between periods. On average, the number of 20 cubic meter invoices companies invested in water in each period registered 30 thousand in 2005, and 33 thousand in 2013, but it was lower in the rest of the period than in both observations. As shown in Table 5, while investments in water decrease in its importance also NRW began to stagnated.

Table 6 presents the information in a slightly different way – by operator and splitting the mean into two periods: 2005–13 and 2011–13. The investment in water divided into fixed assets fell on average during the second period compared with the first. Note that complete coverage in water had been achieved at year 2000 (Table 1). If we conservatively assume an average 50-year life span of the infrastructure, a 1-percent investment per year implies that we are replacing just half of the capital we lose. Unaccounted-For Water is constant in many important operators, such as Andinas (Metropolitan Region). Table 6 also presents the evolution of the 20 cubic meter invoice. The most critical location is Antofagasta, where the invoice costs the same in both periods and is the most expensive in the country.

What priorities should the sector address in the near future? What regulatory options could we explore? One may consider that many of the former have to do with quality, environment, and the like. The maintenance of infrastructure is a priority and NRW control is a vital goal given the remarkable results in coverage. Our econometric results shed some light: it will not be easy since NRW control is expensive in terms of investment. So, we can imagine some responses to the second question: regulations could prioritize maintenance expenditures and a NRW control goal, in addition to adding some resources and duties to that end. For example, we can take advantage of the results in terms of efficiency gains to establish an X-Factor which shares those gains with the clients in the form of lower prices. On the other hand, regulators can induce providers to invest more in maintenance and meet NRW control achievements via a K-factor which recognizes those increased costs.

In our view the tariff formula could take the following form:

P1’ = P0' (as determined based on the “model Company”) * [(1 + Cost Index if > 3 percent accumulated) – X-Factor (calculated as differences in efficiency scores from the best practice of the sample) + K-Factor (to recognize the increased investments in maintenance and NRW control).

Table 5
Evolution of Investments in Water, Non-Revenue Water and Tariffs at sectoral levels.

	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean Investment in Water/Fixed Assets In percent	16.12	12.66	7.98	6.97	6.29	18.23	3.13	3.19	4.15
Mean NRW In percent	32.95	32.31	33.11	32.50	32.75	32.80	32.27	30.92	31.00
Mean 20 cubic meter Invoices In UF	0.93	0.91	0.87	0.90	0.90	0.95	0.86	0.86	0.84
Standard Deviation 20 cubic meter Invoices In UF	0.30	0.28	0.24	0.30	0.29	0.28	0.26	0.27	0.27
Mean 20 cubic meter Invoice Index 2005 = 100	100.00	98.30	94.06	96.29	96.71	102.39	92.69	92.88	90.10
Mean Number of 20 cubic meters Invoices Invested in Water Nº	30,444	28,292	11,800	12,161	17,449	10,705	20,169	22,981	33,440

(Source: Author's Own Elaboration based on SISS data.)

Table 6
Evolution of Investment in Water/Fixed Assets, Non-Revenue Water and Average 20 cubic meter invoice.

Operator	Mean Investment in Water/ Fixed Assets 2005-13 In percent	Mean Investment in Water/ Fixed Assets 2011-13 In percent	Mean Non-Revenue Water 2005-13 In percent	Mean Non-Revenue Water 2011-13 In percent	Average 20 cubic meter Invoice 2005–2013. In UF	Average 20 cubic meter Invoice 2011–13. In UF
Altiplano	22	4	43	39	1.11	1.09
Andinas	1	2	31	31	0.59	0.56
Antofagasta	16	9	26	25	1.41	1.41
Araucania	6	3	45	44	0.83	0.75
Aysen	1	1	40	40	1.42	1.33
Chanar	15	11	39	34	0.94	0.81
Coopagua	4	1	13	13	0.98	1.04
Cordillera	4	1	26	20	0.60	0.56
Decima	3	3	21	20	0.93	0.91
DelValle	34	5	31	31	0.87	0.82
Essal	3	3	38	40	1.06	1.03
Essbio	3	4	37	36	0.72	0.69
Esval	3	2	42	42	0.95	0.91
Magallanes	5	1	15	16	1.12	1.07
Manquehue	10	5	10	11	0.73	0.71
NuevoSur	7	1	44	43	0.77	0.69
Chacabuco	7	2	36	35	0.54	0.50
Smapa	14	4	43	45	0.50	0.49

(Source: Author's Own Elaboration based on SISS data.)

7. Conclusions

Based on a sample of 18 Chilean providers of water and sewerage for the period 2005–13, we computed an input distance function using a stochastic frontier analysis (SFA), to determine the comparative technical efficiency of the providers and its drivers. We performed a True Random Effects model to control for possible unobserved heterogeneity between providers.

We modeled the distribution of the efficiency and find that its dispersion is reducing over time. It would appear that a catch-up process has been taking place over the years. While there was no technical change at the sectoral level as a whole, the firms that achieved better results were the most lagged at the beginning. We also modeled the error term and find that time was not important, implying that the firms did not become more similar; instead, they depend on their type of clients (if the average consumption increases with non-residential clients, as we assume). The higher the average consumption, the more different the operators are.

High levels of NRW reduce the input requirements. Its coefficient suggests that costs associated with NRW detections, repairs and controls are more substantial than the costs of producing and distributing additional cubic meters of water. A 10-percent reduction in NRW implies a 2.6-percent increase in the input vector. Although the investments coefficient has a very low value, it is positive and statistically significant, that is, if the investments were doubled, the input requirement would shrink by 1 percent.

Current levels of NRW, even high, are implicitly tolerated. Economic analysis suggests that the benefits of reducing NRW have to be balanced with the costs of doing so. Then, there is an economic optimal level for the losses. On the other hand, the long term ecological consequences of water pumping must be taking into consideration, yielding probably less tolerable levels of NRW than the pure economic cost benefit analysis suggests.

The sector is highly intensive in capital, since labor only contributes 4 percent to output. We find increasing returns to scale, although the functional form we employ does not allow us to explore its evolution over time. The time trend is not significant, implying no technical change in the period, but we can observe a reduction in technical inefficiency over the years.

What priorities could the sector address in the near future? What regulatory options could we explore? We suggest that the maintenance of infrastructure is a priority and NRW control is a vital goal given the remarkable results in coverage. One regulatory response could be to prioritize the former and to add some resources and duties to that end. For example, we can take advantage of the results in terms of efficiency gains to establish an X-Factor which shares part of those gains with the clients in the form of lower prices. On the other hand, regulators can induce providers to invest more in maintenance and meet NRW control achievements via a K-factor which recognizes the associated increased costs.

Appendix

Firm	Locality
Altiplano	Iquique
Andinas	Gran Santiago
Antofagasta	Antofagasta
Araucania	Temuco
Aysen	Coyhaique
Chanar	Copiapo
Coopagua	Santo Domingo
Cordillera	Aguas Cordillera
Decima	Valdivia
DelValle	La Serena
Essal	Puerto Montt
Essbio	Concepcion
Esval	Valparaiso
Magallanes	Punta Arenas
Manquehue	Santa Maria de Manquehue
NuevoSur	Curico
Chacabuco	Colina Esmeralda
Smapa	Maipú

Year	1 UF = Chilean pesos	1 US$ = Chilean pesos	1 UF = US$
2005	17975.97	560	32.11
2006	18336.38	530	34.57
2007	19622.66	522	37.60
2008	21453.00	523	41.02
2009	20943.00	559	37.49
2010	21455.55	511	41.96
2011	22994.00	484	47.55
2012	22841.00	487	46.95
2013	22841.00	496	46.09

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