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# Assessing the efficiency of Chilean water and sewerage companies accounting for uncertainty

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ABSTRACT

Efficiency assessment of water and sewerage companies (WaSCs) has attracted considerable attention both for water company managers and water regulators. Within the methodological approaches that can be applied to estimate efficiency scores, data envelopment analysis (DEA) is the most widely applied technique. In spite of the positive features of DEA, it presents a major drawback which is its deterministic nature. In other words, conventional DEA models do not account for uncertainty in the data. To overcome this limitation, we assess, for the first time, the efficiency of a sample of Chilean WaSCs by using a DEA model with statistical tolerance in the data. Hence, 81 efficiency scores are estimated for each WaSC rather than a single score as with conventional DEA models. The results illustrate that outputs exhibit larger uncertainty than inputs. Moreover, WaSCs efficiency scores change significantly under the best-case and worst-case scenarios. The ranking of the WaSCs allows for the identification of which of them has the highest performance based on their efficiency scores. This information is essential to enhance efficiency and innovation in the water industry. Moreover, the introduction of uncertainty in the efficiency assessment allows for the prediction and ranking of future performance of WaSCs.


## 1. Introduction

Over the last few years, efficiency assessment in water industry has attracted considerable attention by researchers, water companies and regulators (Romano and Guerrini, 2011). Improvement of the efficiency of water companies is desirable allowing for cost reduction, increase profits of water companies, and/or decreased prices paid by consumers for water and sewerage services (Molinos-Senante et al., 2015a). Hence, improvement of efficiency is a major policy objective of water companies and regulators (Carvalho and Marques, 2011).

Most studies that assess the efficiency of water utilities employ the non-parametric data envelopment analysis (DEA) (e.g., García-Sánchez, 2006; Berg, 2010; Molinos-Senante et al., 2014). The advantages of DEA are that: (i) it does not require assumptions about the functional relationship between inputs and outputs; (ii) it allows for the estimation of the efficiency of productive decision making units (DMUs) which use multiple inputs to produce multiple outputs; and (iii) the weights to aggregate inputs and outputs are generated endogenously which minimizes the subjectivity of the assessment (Guerrini et al., 2013).

In spite of these advantages, DEA is not exempt of limitations. The deterministic nature of DEA is a major drawback, as statistical inferences cannot be drawn from conventional DEA models (Ananda, 2014) and efficiency scores are highly sensitive to atypical observations and data errors (De Witte and Marques, 2010). To take into account uncertainty in the efficiency assessment, several methodological approaches have been developed (Li, 1998; Simar and Wilson 1998, 2007; Cazals et al., 2002; Daraio and Simar, 2005; Bonilla et al., 2004).

In spite of the importance of considering uncertainty in efficiency assessment in the framework of water utilities, the information gap in the literature is evident. To the best of our knowledge, only De Witte and Marques (2010); Ananda (2014) and See (2015) applied bootstrapping techniques to evaluate the

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efficiency of water companies. Sala-Garrido et al. (2012) used DEA with tolerances model to assess the efficiency of a sample of Spanish wastewater treatment plants accounting for uncertainty. In view of the few empirical applications which deal with the uncertainty issue in the performance measurement of water companies, there is a clear need for advancing in this research stream.

Efficiency scores are often used to identify which units use resources most efficiently. However, to make informed decisions the evaluated DMUs should be ranked in terms of efficiency. According to DEA methodology, several DMUs can be identified as efficient and therefore, they cannot be ranked directly by using their efficiency scores (Esmaeilzadeh and Hadi-Vencheh, 2015). Hence, several methodological approaches have been proposed to deal with the issue of ranking DMUs (Adler et al., 2002) such as cross-efficiency (Sexton et al., 1986), benchmarking approaches (Torgersen et al., 1996), multivariate statistical tools (Friedman and Sinuany-Stern, 1997), super-efficiency (Andersen and Petersen, 1993), and efficiency indicators (Boscá et al., 2011). While each one of these methodological approaches has advantages and shortcomings, the system of indicators proposed by Boscá et al. (2011) were developed specifically to rank DMUs when the efficiency assessment accounts for uncertainty in the inputs and/or outputs.

Against this background, the objectives of this paper are threefold. The first one is to identify which variables (inputs and/or outputs) are the most sensitive to changes, i.e., which have the largest potential uncertainty. The second objective is to evaluate the efficiency of a sample of water and sewerage companies (WaSCs) accounting for uncertainty. The empirical application focuses on the 23 main Chilean WaSCs for 2014. The third objective of this paper is to rank the evaluated WaSCs to support the decision process of water regulators.

This paper contributes to the current strand of literature in the field of water companies' performance measurement by computing the efficiency scores of WaSCs introducing statistical tolerances in the data and by ranking the WaSCs based on their efficiency scores. To the authors' knowledge, this is the first study that applies DEA with a tolerances model to assess the efficiency of a sample of WaSCs accounting for uncertainty. Chile presents an interesting case within the context of this research since it has long been a pioneer in the privatization of water and sewerage services. Chile has been by far the most successful case of water and sewerage services privatization after the privatization of the English and Welsh water companies in the 1980s (Lee and Floris, 2003). Moreover, because Latin America could be described as being situated at a medium level in terms of coverage and quality of water and sewerage services, water managers and authorities in other Latin American countries can learn some lessons from the Chilean case (Molinos-Senante et al., 2015a, 2015b, 2015c; Molinos-Senante and Sala-Garrido, 2015). On the other hand, the Chilean tariff law introduced the concept of an efficient water and sewerage operator model, so as to incentive providers to be technically and economically efficient. Additionally, privatization of WaSCs in Chile have led to lower rates in the long term since its rate setting system has allowed for the transfer of efficiencies to final prices. Thus, it is of interest to assess the effectiveness of these regulatory reforms on WaSCs' efficiency, so as to extract lessons and implications for its potential replication.

From a policy perspective, this study is of great interest both for WaSCs' managers and water regulators. On the one hand, the inclusion of variability in the data allows WaSCs that should be on alert to be identified, since small changes in the inputs and/or outputs will cause a significant reduction in their efficiency. On the other hand, the ranking of the WaSCs based on efficiency scores is essential for water regulators to promote competition between the WaSCs reducing monopoly problems. This issue is essential to ensure the sustainability of WaSCs over time and to provide improved water and sewerage services to citizens.

## 2. Methodology

### 2.1. Efficiency assessment

DEA is a non-parametric method based on linear programming that allows for the construction of the efficient production frontier based on the inputs and outputs of the DMUs (Charnes et al., 1978). The relative efficiency for each DMU is calculated by comparing its inputs and outputs in relation to the rest of the units (Molinos-Senante et al., 2014). In other words, DEA produces measurements of the relative inefficiency of each DMU when compared to what amounts to an industry's best practice output/input ratio (Cooper et al., 2004). Further details on DEA methodology are provided by Cooper et al. (2007) and Zhu (2015).

Traditional DEA models can be input-oriented or output-oriented. Accordingly, when a DMU reaches the maximum output given a set of inputs (output-oriented DEA) or uses a minimum of inputs to produce a given set of outputs (input-oriented DEA) it is placed on the production frontier and therefore, it is efficient (Cooper et al., 2004). The selection of the orientation depends on the objective of the efficiency evaluation. Following past evidence (Guerrini et al., 2011; Mahmoudi et al., 2012; Carvalho and Marques, 2014), in this study an input orientation was adopted since the aim of the WaSCs is to provide water and sewerage services minimizing the use of inputs.

In DEA framework, the production frontier can be estimated by considering constant returns to scale (CRS) and variable returns to scale (VRS) technologies. The CRS approach assumes that all DMUs operate at an optimum level. On the other hand, the VRS approach compares DMUs with a similar scale. Molinos-Senante et al. (2015a) investigated whether Chilean WaSCs operate under CRS or VRS technology. They concluded that the technology of the WaSCs in Chile is overall CRS at a confidence interval of 95%. Hence, in this paper we assumed that the DMUs evaluated have CRS technology.

Given $k = 1, 2 \ldots, n$ DMUs (WaSCs in our case study), teach one using a vector of $M$ inputs $x_k = (x_{1k}, x_{2k}, \ldots, x_{Mk})$ to produce a vector of $S$ outputs $y_k = (y_{1k}, y_{2k}, \ldots, y_{Sk})$, according to the model DEA-CRS, the measure of efficiency $\theta$ is obtained by solving for each DMU $k_0$ the following linear programming problem:

$$\begin{aligned} & \text{Min}\theta \\ & s.t. \\ & \sum_{k=1}^{n} \lambda_k x_{ik} \le \theta x_{ik_0} \quad 1 \le i \le M \\ & \sum_{k=1}^{n} \lambda_k y_{rk} \ge y_{rk_0} \quad 1 \le r \le S \\ & \lambda_k \ge 0 \quad 1 \le k \le n \end{aligned} \tag{1}$$

where $\lambda_k$ is a vector of intensity. The measure of efficiency $\theta$ is bounded between 0 and 1. It is considered that a DMU (WaSC in our case study) is efficient if $\theta = 1$, while it is inefficient if $0 \le \theta < 1$. The difference between the score $\theta$ and the value of 1 can be considered to be the potential reduction in inputs to obtain the same set of outputs.

Eq. (1) illustrates the traditional DEA model developed by Charnes et al. (1978) with input orientation and CRS technology assumption. In essence, the efficient input–output levels in DEA are those which are not dominated by the others in the reference set. The applied analysis presupposes data determinism and, so, any mistake or inaccuracy in the measure could alter the efficiency index results, a common limitation of efficiency analyses based on DEA.

To overcome this limitation, we applied a DEA model with statistical tolerance developed by Bonilla et al. (2004) which has been applied by other authors such as Boscá et al. (2009, 2011);