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Changes to The Productivity of Water Companies: Comparison of Fully Private and Concessionary Water Companies

Alexandros Maziotis[1,2] · Ramon Sala-Garrido[3] · Manuel Mocholi-Arce[3] · Maria Molinos-Senante[1,4]

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Abstract

The water industry encompasses a wide variety of water companies operating with different production technologies. This study evaluated and compared changes to the productivity of several fully private water companies (FPWCs) and concessionary water companies (CWCs). Specifically, the cost Malmquist productivity index was estimated by integrating inputs, outputs and environmental variables. A non-parametric approach was used by applying data envelopment analysis. This approach allowed us to quantify the parameters driving changes to productivity as cost efficiency change (technical and allocative efficiency), cost scale efficiency and cost technical change (technical change and input price effect). Through breaking down the cost Malmquist productivity index, relevant information for supporting decision making process by water companies is possible. To further evaluate the impact of water company heterogeneity on productivity change, the changes (convergence versus divergence) to productivity between group and meta-frontiers was estimated. The approach was applied empirically on a sample of 22 water companies in Chile during 2010–2017. The results showed that the productivity of both FPWCs and CWCs improved over time, with FPWCs performing better compared to CWCs. The main drivers of productivity growth for both types of water companies were scale efficiency, technical efficiency and input price effect. Thus, water companies in Chile could improve productivity by moving to a cost-efficient allocation of their resources. The rate of productivity convergence was higher for CWCs compared to FPWCs. The approaches developed in this study provide information that could be used by water managers to better understand what drives productivity and, thus, delineate strategies to improve performance over time.

Keywords Cost Malmquist productivity · Meta frontier · Productivity gap · Performance · Water utilities · Chile

✉ Maria Molinos-Senante
mmolinos@uc.cl

Extended author information available on the last page of the article

1 Introduction

Globally, the water industry has undergone several reforms over the last decades. Such changes include the promotion of privatization and mergers among water utilities, along with the introduction of new policies that could break up the water and wastewater supply chain into smaller separate parts. These reforms aim to enhance the efficiency of water utilities, which, in turn, should benefit customers in the form of lower tariffs. Thus, assessing the efficiency and productivity of the water industry has become a priority for both the regulated companies and regulators, because the outcome of such analyses is integral in the process of setting tariffs (Marques 2011; Higuerey et al. 2017; Centrulo et al. 2020).

Even though several reforms have been implemented, the water industry encompasses different types of water utilities that potentially have different structural forms, or provide different services. These differences should be accounted for when assessing performance (e.g. De Witte and Marques 2009; Molinos-Senante and Sala-Garrido 2016; Molinos-Senante and Maziotis 2019), as they likely operate using different production technologies. Thus, an appropriate measure to evaluate the efficiency and productivity growth of companies is required to account for this heterogeneity (Suarez-Varela et al. 2017).

The meta-frontier approach proposed by Hayami (1969) and Hayami and Ruttan (1970), and further developed by O'Donnell et al. (2008), allows the comparison of units (water companies in this study) that operate under different production frontiers. This methodological approach overcomes issues in the comparability of analysed units (Hayami 1969). The meta-frontier concept envelops different production (or cost) frontiers, and considers all possible heterogeneity among the units (Wang et al. 2013). Battese et al. (2004), O'Donnell et al. (2008) and Huang et al. (2014) developed several techniques to measure efficiency using group technology, meta technology and technology gaps. In the context of the water industry, several studies have employed non-parametric techniques, such as Data Envelopment Analysis (DEA), to measure efficiency and productivity change using the meta-frontier concept (De Witte and Marques 2009; Molinos-Senante and Sala-Garrido 2016; Molinos-Senante et al. 2017). Molinos-Senante and Maziotis (2019) also employed parametric (econometric) techniques, including Stochastic Frontier Analysis (SFA), to measure efficiency using the meta-frontier framework.

The advantage of non-parametric techniques over parametric ones is that they do not require a functional form for the technology to be specified (Suarez-Varela et al. 2017). Non-parametric techniques also easily include multiple inputs and outputs, and do not make any assumptions about the distribution of inefficiency (Huang et al. 2015). Thus, in the current study, we employed non-parametric techniques to evaluate the efficiency and productivity of water companies using the meta-frontier concept. Our case study focused on the water industry in Chile, which was privatised during 1998–2004. The end of the privatization process led to the establishment of two types of companies: (1) fully private water companies (FPWCs), which are responsible for providing water and sewerage services over an indefinite time period; and (2) concessionary water companies (CWCs), which also provide both water and sewerage services, but for a limited time period. We focused on the privatized water industry in Chile because there has been limited evaluation of its performance based on group heterogeneities. To the best of our knowledge, only Molinos-Senante and Sala-Garrido (2016) applied the meta-frontier concept to compare the efficiency between FPWCs and CWCs. Subsequently, Sala-Garrido et al. (2019) measured changes to the productivity of both types of water companies. However, the impact of several drivers that may affect the performance of water companies was not included in these previous studies. We aimed to fill this gap in the literature by applying a methodology that provides a more detailed understanding of what drives productivity in the privatized water industry of Chile, by taking into account allocative and scale inefficiency, along with group heterogeneities.

This study aimed to compare changes to the productivity of a sample of FPWCs and CWCs in the water industry of Chile during 2010–2017. We also compared cost group and meta-frontier productivity results, analysing them based on the type of water company. Thus, this study aims to provide the first estimate of cost using the meta frontier Malmquist productivity index. This approach allows changes to productivity to be broken into in several drivers, providing essential information the managers and regulators of water companies. Hence, this study provides a novel approach for comparing changes to productivity in water companies, and identifying the components of productivity. Our results are expected to provide insights on measurements of convergence or divergence in productivity between groups and meta-frontiers, and the sources of these patterns.

2 Methodology

2.1 Estimation of Technical, Cost and Allocative Efficiency

This section presents the methodology used to estimate the cost groupings and meta-frontier Malmquist productivity indices, including drivers. Indices were derived by estimating distance and cost functions based on the technology of each group j and meta-technology M, which included all groups (i.e., the entire industry). The technology was defined as the set of each group j ($P_{j,t}$) and entire industry $\left(P_{M,t}\right)$ respectively, which used a set of input vectors (x) to produce a set of output vectors (y) at any time, t as follows:

$$P_{j,t}(x,y) = \left(\left(x_t, y_t\right) | x_t can\ produce\ y_t where\ t = 1, \dots, T\ and\ j = 1, \dots, J\right) \tag{1}$$

$$P_{M,t}(x,y) = \left(\left(x_t, y_t\right) | x_t can\ produce\ y_t where\ t = 1, \dots, T\right) \tag{2}$$

The production technology (frontier) is unknown, and is estimated using data from a sample of units (water companies) (Coelli et al. 2013). This was accomplished with input distance functions (Marques et al. 2014). Thus, the input distance functions of the group frontier $j\left(D_{j,t}\right)$ and the meta frontier $M\left(D_{M,t}\right)$ were, respectively, defined at any time t, as follows:

$$D_{j,t}\left(y_t, x_t\right) = \max\left\{ : \gamma > 0\left(\frac{x}{\gamma}\right), y \in P_{j,t}\right\} \tag{3}$$

$$D_{M,t}\left(y_t, x_t\right) = \max\left\{ : \gamma > 0\left(\frac{x}{\gamma}\right), y \in P_{M,t}\right\} \tag{4}$$

where γ is a scalar (distance parameter)≥ 1, being equal to 1 if the unit is technically efficient (Erbetta and Pretaglia 2011). The technical efficiency of a unit was defined using the group technology $j\left(TE_{j,t}\right)$ and the meta technology $\left(TE_{M,t}\right)$, respectively, at any time t, as follows:

$$TE_{j,t} = \left[D_{j,t}\left(y_t, x_t\right)\right]^{-1} \tag{5}$$

$$TE_{M,t} = \left[D_{M,t}\left(y_t, x_t\right)\right]^{-1} \tag{6}$$

When input prices are available, the objective of the unit was to minimise the costs of production for a given level of output. In this case, the minimum cost or cost frontier using the group technology $(C_{j,t}(y_t, w_t))$ and meta technology $\left(C_{M,t}(y_t, w_t)\right)$ at any time t were, respectively, defined as (Huang et al. 2015):

$$C_{j,t}\left(y_t, w_t\right) = min\left\{w_t x_t | \left(x_t, y_t\right) \in P_{j,t}, w_t > 0\right\} \tag{7}$$

$$C_{M,t}\left(y_t, w_t\right) = min\left\{w_t x_t | \left(x_t, y_t\right) \in P_{M,t}, w_t > 0\right\} \tag{8}$$

The cost efficiency of any unit was defined as the minimum cost (cost frontier) divided by the actual cost. In terms of using the group technology j and meta technology M, the cost efficiency at any time t $(CE_{j,t}, CE_{M,t})$ was, respectively, defined as:

$$CE_{j,t} = \frac{C_{j,t}\left(y_t, w_t\right)}{w_t x_t} \tag{9}$$

$$CE_{M,t} = \frac{C_{M,t}\left(y_t, w_t\right)}{w_t x_t} \tag{10}$$

A unit should not only be technically efficient (i.e., by minimising its inputs for a given level of output), but should also be allocatively efficient (i.e., by choosing the appropriate combination of inputs that minimise its costs). In this case, the unit would be cost efficient. Thus, the allocative efficiency of a unit was defined as the efficient combination of inputs given its input prices, using the group technology $j\left(AE_{j,t}\right)$ and meta technology $\left(AE_{M,t}\right)$, respectively, at any time t as:

$$AE_{j,t} = \frac{CE_{j,t}}{TE_{j,t}} \tag{11}$$

$$AE_{M,t} = \frac{CE_{M,t}}{TE_{M,t}} \tag{12}$$

2.2 Estimation of the Group and Meta-frontier Cost Malmquist Productivity Index

The cost efficiency of the group and meta-frontier cost Malmquist productivity index measures changed between two time periods, t and $t+1$. First, we evaluated the cost group frontier Malmquist productivity index (CGMPI), previously developed by Maniadakis and Thanassoulis (2004). This index was defined as:

$$
\begin{aligned}
CGMPI_{j,t,t+1} &= \left[\frac{CE_{j,t}^{CRS}\left(y_{t+1}, x_{t+1}, w_t\right)}{CE_{j,t}^{CRS}\left(y_t, x_t, w_t\right)} \times \frac{CE_{j,t+1}^{CRS}\left(y_{t+1}, x_{t+1}, w_{t+1}\right)}{CE_{j,t+1}^{CRS}\left(y_t, x_t, w_{t+1}\right)} \right]^{0.5} \\
&= \left[\frac{C_{j,t}^{CRS}\left(y_{t+1}, w_t\right)/w_t x_{t+1}}{C_{j,t}^{CRS}\left(y_t, w_t\right)/w_t x_t} \times \frac{C_{j,t+1}^{CRS}\left(y_{t+1}, w_{t+1}\right)/w_{t+1} x_{t+1}}{C_{j,t+1}^{CRS}\left(y_t, w_{t+1}\right)/w_{t+1} x_t} \right]^{0.5} \\
&= \left[\frac{C_{j,t+1}^{VRS}\left(y_{t+1}, w_{t+1}\right)/w_{t+1} x_{t+1}}{C_{j,t}^{VRS}\left(y_t, w_t\right)/w_t x_t} \right] \times \left[\frac{\frac{C_{j,t+1}^{VRS}\left(y_t, w_{t+1}\right)}{C_{j,t+1}^{CRS}\left(y_t, w_{t+1}\right)}}{\frac{C_{j,t+1}^{VRS}\left(y_{t+1}, w_{t+1}\right)}{C_{j,t+1}^{CRS}\left(y_{t+1}, w_{t+1}\right)}} \times \frac{\frac{C_{j,t}^{VRS}\left(y_t, w_t\right)}{C_{j,t}^{CRS}\left(y_t, w_t\right)}}{\frac{C_{j,t}^{VRS}\left(y_{t+1}, w_t\right)}{C_{j,t}^{CRS}\left(y_{t+1}, w_t\right)}} \right]^{0.5} \\
&\quad \times \left[\frac{C_{j,t}^{VRS}\left(y_{t+1}, w_t\right)/w_t x_{t+1}}{C_{j,t+1}^{VRS}\left(y_{t+1}, w_{t+1}\right)/w_{t+1} x_{t+1}} \times \frac{C_{j,t}^{VRS}\left(y_t, w_t\right)/w_t x_t}{C_{j,t+1}^{VRS}\left(y_t, w_{t+1}\right)/w_{t+1} x_t} \right]^{0.5} \\
&= CEC_j^{VRS} \times CSEC_j \times CTC_j^{VRS}
\end{aligned}
\tag{13}
$$

In Eq. (13), if $CGMPI_{j,t,t+1}$ is greater than one, it indicates that the unit improved its productivity over time. In contrast, a value less than one indicates that unit productivity has deteriorated. A value equal to one indicates no change to unit productivity over time. Changes to CGMPI could be separated into three factors; namely: i) changes to cost efficiency $\left(CEC_j^{VRS}\right)$, ii) changes to cost scale efficiency $\left(CSEC_j\right)$ and; iii) changes to cost technical change $\left(CTC_j^{VRS}\right)$. The first driver measures the level of catch-up to the cost group frontier from period t to period $t+1$. It shows whether the cost efficiency of the unit improved or deteriorated relative to the most cost efficient unit within its group. Thus, if $CEC_j^{VRS} > (<)1$, then the unit achieved cost efficiency gains (losses). The second driver, $CSEC_j$, captures the impact of changing the scale of operations on productivity. The loss in the optimal scale size is captured by cost scale efficiency change. If $CSEC_j > 1$, then the unit moved closer to (or for < 1, away from) the group optimal cost scale between the two time periods, t and $t+1$ (Cho 2018). The last driver of the CGMPI, CTC_j^{VRS}, measures technological change, which is the cost efficiency of a unit generating an identical output using the group technologies of period t and $t+1$ (Huang et al. 2015). If cost technical change is greater than one, then technical progress occurred. In contrast, a value less than one indicates technical regression. Changes to group cost efficiency and technical change could be separated into several factors, as shown in Eqs. (14) and (15). Thus, changes to the cost of production between time periods t and $t+1$ could be attributed to changes in technical efficiency and allocative efficiency, and changes in technology and input prices (Huang et al. 2015).

$$
\begin{aligned}
CEC_j^{VRS} &= \left[\frac{\frac{C_{j,t+1}^{VRS}\left(y_{t+1}, w_{t+1}\right)}{w_{t+1} x_{t+1}}}{\frac{C_{j,t}^{VRS}\left(y_t, w_t\right)}{w_t x_t}} \right] = \left[\frac{D_{j,t}^{VRS}\left(y_t, x_t\right)}{D_{j,t+1}^{VRS}\left(y_{t+1}, x_{t+1}\right)} \right] \\
&\quad \times \left[\frac{D_{j,t+1}^{VRS}\left(y_{t+1}, x_{t+1}\right) \times C_{j,t+1}^{VRS}\left(y_{t+1}, w_{t+1}\right)/w_{t+1} x_{t+1}}{D_{j,t}^{VRS}\left(y_t, x_t\right) \times C_{j,t}^{VRS}\left(y_t, w_t\right)/w_t x_t} \right] = TEC_j^{VRS} \times AEC_j^{VRS}
\end{aligned}
\tag{14}
$$

The first part of Eq. (14) measures changes in technical efficiency, and shows if a unit improved its daily management practices over time. If $TEC_j^{VRS} > 1$, then the unit caught-up (moved closer) to the group frontier by improving its technical efficiency relative to the most technical efficient company within its group. In contrast, a value less than one indicates a loss in technical efficiency. The second part of Eq. (14) is the change to allocative efficiency, which captures the degree of catch-up regarding the optimum allocation of resources over time based on prices (Huang et al. 2015). If $AEC_j^{VRS} > 1$, then the unit moved closer to the cost-efficient allocation of its inputs. In contrast, a value of less than one indicates that the adjustments to the combined input parameters were not efficient over time.

$$
\begin{aligned}
CTC_j^{VRS} &= \left[\frac{C_{j,t}^{VRS}(y_{t+1}, w_t)/w_t x_{t+1}}{C_{j,t+1}^{VRS}(y_{t+1}, w_{t+1})/w_{t+1} x_{t+1}} \times \frac{C_{j,t}^{VRS}(y_t, w_t)/w_t x_t}{C_{j,t+1}^{VRS}(y_t, w_{t+1})/w_{t+1} x_t} \right]^{0.5} \\
&= \left[\frac{D_{j,t+1}^{VRS}(y_{t+1}, x_{t+1})}{D_{j,t}^{VRS}(y_{t+1}, x_{t+1})} \times \frac{D_{j,t+1}^{VRS}(y_t, x_t)}{D_{j,t}^{VRS}(y_t, x_t)} \right]^{0.5} \\
&\quad \times \left[\frac{C_{j,t}^{VRS}(y_{t+1}, w_t) D_{j,t}^{VRS}(y_{t+1}, x_{t+1})/w_t x_{t+1}}{C_{j,t+1}^{VRS}(y_{t+1}, w_{t+1}) D_{j,t+1}^{VRS}(y_{t+1}, x_{t+1})/w_{t+1} x_{t+1}} \times \frac{C_{j,t}^{VRS}(y_t, w_t) D_{j,t}^{VRS}(y_t, x_t)/w_t x_t}{C_{j,t+1}^{VRS}(y_t, w_{t+1}) D_{j,t+1}^{VRS}(y_t, x_t)/w_{t+1} x_t} \right]^{0.5} \\
&= \left[\frac{TE_{j,t}^{VRS}(y_{t+1}, x_{t+1})}{TE_{j,t+1}^{VRS}(y_{t+1}, x_{t+1})} \times \frac{TE_{j,t}^{VRS}(y_t, x_t)}{TE_{j,t+1}^{VRS}(y_t, x_t)} \right]^{0.5} \\
&\quad \times \left[\frac{AE_{j,t}^{VRS}(y_{t+1}, x_{t+1}, w_t)}{AE_{j,t+1}^{VRS}(y_{t+1}, x_{t+1}, w_{t+1})} \times \frac{AE_{j,t}^{VRS}(y_t, x_t, w_t)}{AE_{j,t+1}^{VRS}(y_t, x_t, w_{t+1})} \right]^{0.5} = TC_j^{VRS} \times IPE_j^{VRS}
\end{aligned}
\tag{15}
$$

Equation (15) shows that changes to the cost of technology could be attributed to two factors: i) shifts in the production frontier and; ii) shifts in relative input prices (Cho 2018). Thus, the first part of Eq. (15), TC_j^{VRS}, is the pure technical change, in which a value greater than one indicates improvements to technology, whereas a value less than one indicates deterioration in technology. The second part of Eq. (15) is the input price effect, IPE_j^{VRS}. This parameter measures the impact of change to the prices of resources using the minimum cost between time periods t and $t+1$ (Cho, 2018). A value greater than one indicates a beneficial input price effect, which reduces the cost efficiency of producing an output between the two periods. In contrast, if IPE_j^{VRS} is less than one, it indicates an unfavourable input price effect is in place, which negatively impacts cost efficient production (Huang et al. 2015).

The meta-frontier denotes the best possible production frontier across all groups, and includes all of the group-specific frontiers (i.e., the entire industry) over a particular time period (Huang et al. 2015). Similarly, we defined and separated out the cost meta frontier Malmquist productivity index (CMMPI) between time periods t and $t+1$ under VRS technologies (see appendix for details).

The computation of the CGMPI and CMMPI requires several distance and cost functions to be calculated. Non-parametric methods (i.e., DEA) were used, following Maniadakis and Thanassoulis (2004), Huang et al. (2015) and Cho (2018). These methods require the optimisation of several linear programming models. The appendix presents the linear programming models employed to calculate the input-oriented distance functions and minimum costs regarding the group and meta technologies used to compute the cost Malmquist productivity indices and their components.

3 Sample Data and Description

Our empirical study focused on the water and sewerage industry of Chile, which was privatised during 1998–2004, forming fully private and concessionary water companies. Our sample consisted of 22 water and sewerage companies, of which 11 were fully private and 11 were concessionary. The data used in this study covered the 2010–2017 period, and were downloaded from the website of the national water economic regulator namely "Superintendencia de Servicios Sanitarios" (SISS).[1]

Based on past evidence of the water industry in Chile and elsewhere (e.g., Berg and Marques 2011; See 2015; Molinos-Senante and Sala-Garrido 2016; Romano et al. 2017; Li and Phillips 2017; Goh and See 2021), we used the volume of water supplied measured in cubic metres per year and annual number of customers receiving wastewater treatment service as the outputs. To reflect changes in the quality of drinking water and wastewater treatment, we multiplied both outputs with a drinking water quality indicator and the number of customers receiving wastewater treatment with a wastewater treatment quality indicator. Both quality indicators were developed by the Chilean regulator (SISS), and have values ranging between zero and one. A value of one indicates that the water company met the quality standards regarding the quality of potable water and treatment of wastewater before being discharged (Molinos-Senante and Sala-Garrido 2016). By contrast, a value lower than one means that the water company had some deficiencies regarding quality issues, and the generation of outputs were penalised from the productivity perspective.

Inputs included the operating expenditure of water and sewerage services [measured in Chilean pesos per year (CLP/year)] and network length [measured in kilometres (km)] as a proxy for capital quantity (See 2015; Mellah and Ben Amor 2016; Cetrulo et al. 2019; Goh and See 2021). Following past practices, the price for network length was defined as the ratio of capital expenditure and total network length (Correira and Marques 2011). Consistent with past practices, the price of operating expenditure was approximated from the Chilean producer price index, which was obtained from national statistics (Mellah and Ben Amor 2016). Table 1 shows the descriptive statistics used for the period of study.

4 Results and Discussion

4.1 Cost Group Malmquist Productivity Index

Figure 1 shows the CGMPI for the 22 water companies (all) evaluated in Chile, including FPWCs and CWCs. On average, the cost productivity of FPWCs and CWCs improved over time by 1.4% and 2.2%, respectively. Overall, the productivity of the water industry in Chile improved by 1.8% per year. Both types of companies achieved gains in their productivity over time, with the concessionary companies being slightly more productive compared to the fully private ones. On average, the productivity of CWCs remained positive for most of the evaluated years. It increased at a rate of 6.7% and 1.4% per year during 2010–11 and 2011–12, respectively. However, productivity followed a downward trend in the subsequent years, and was lowest in 2013–14. In the last two time periods of the study, productivity increased at an annual rate of 6.3% on average. The productivity of FPWCs

[1] Interested readers can consult the SISS website at: www.siss.gob.cl

Table 1 Descriptive statistics

Variables	Units	Full private water companies				Concessionary water companies			
		Mean	SD	Min	Max	Mean	SD	Min	Max
Volumes of water delivered	10^3 m^3/year	68,164	120,605	1064	458,025	24,699	17,376	635	52,739
Customers with access to waste-water treatment	nr	963,199	1,712,803	12,068	6,451,025	391,086	275,034	5835	759,365
Network length	km	4488	6478	74	21,859	2092	1363	102	4522
Operating expenditure	CLP/year	37,608,373	54,486,831	799,873	201,122,273	22,062,324	15,902,554	1,133,457	65,070,422
Price for network length	CLP/km	4653	4286	725	19,277	3407	3559	43	19,732
Price for operating expenditure	Index	0.905	0.070	0.804	1.000	0.905	0.070	0.804	1.000
Drinking water quality	Index	0.974	0.050	0.755	1.000	0.974	0.052	0.700	1.000
Wastewater treatment quality	Index	0.964	0.058	0.667	1.000	0.974	0.041	0.807	1.000

Total expenditure is in 2017 prices

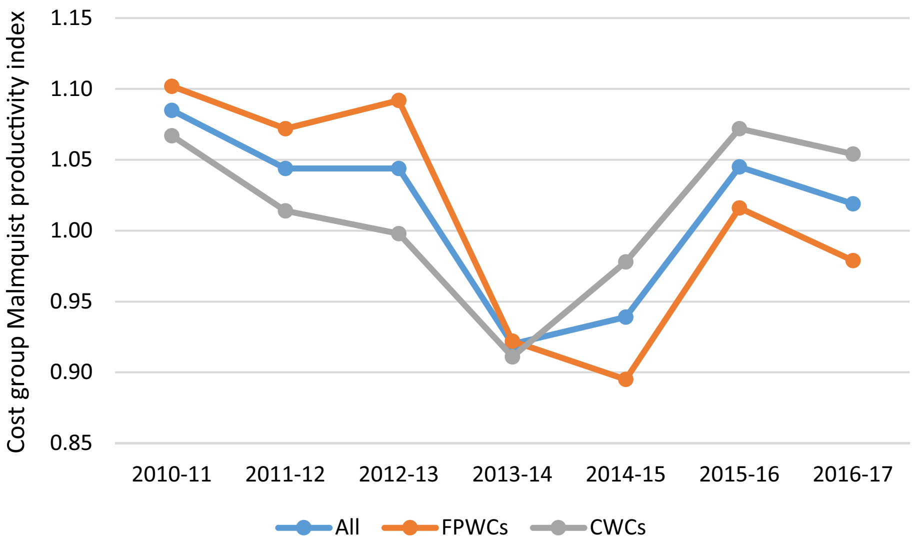

Fig. 1 Evolution of the cost productivity change for each group of Chilean water companies

improved at an annual rate of 8.8% on average during 2010–13. However, subsequently, productivity decreased, with the exception of 2015–16.

To better understand what drove changes to the productivity of the water companies, we examined the sources (Figs. S1 and S2 in supplemental material; Table 2). On average, during 2010–17, CSE, TEC and IPE contributed positively to the productivity of FPWCs, whereas AEC and TC adversely impacted productivity (Fig. S1). In particular, TEC had gains at a rate of 0.8% per year, on average, which were more apparent during 2013–17. This result indicated that less efficient FPWCs improved their efficiency toward the most efficient water company within their group. Small gains in relative group-specific input prices indicate that changes to the price of capital (network length) and operating expenditure had small but positive impacts on minimum production costs and, thus, productivity. However, this phenomenon did not lead to the cost efficient allocation of capital and operating costs, as demonstrated by the allocative efficiency effect. Moreover, CTC remained stable and positive throughout the entire period, indicating that minimal technical progress occurred. However, more technological developments are needed, as shown by the level of technical change. CSE had the greatest impact on the productivity of FPWCs, increasing at an average annual rate of 1.4%. Thus, average FPWCs moved closer to the most optimal scale of production within this group. Although scale efficiency change substantially increased from 2010–11 to 2013–14, but subsequently decreased. Overall, FPWCs need to place greater effort in improving resource allocation and should adopt best group-specific technology practices to improve cost efficiency and productivity within their group.

The results on cost group frontier productivity for average CWCs indicated that considerable gains in CSE and TEC positively impacted productivity, on average (Fig. S2). TC and IPE also positively contributed to productivity, but only had small impacts. Allocative efficiency was the sole negative determinant of CWC productivity. Over time, CSE and TEC increased at an annual rate of 2.6% and 1.5%, respectively. Improving day-to-day operations and adjustments in the scale of operations improved productivity over time within this group. However, CWCs did not appear to be cost efficient, as changes in the

Table 2 Decomposition of the cost group frontier Malmquist productivity index (CGMPI) and its drivers over time

	Productivity change and its drivers		2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
All water companies	CGMPI		1.085	1.044	1.044	0.92	0.939	1.045	1.019
	CEC	*TEC*	0.971	1.054	0.955	1.052	1.028	0.976	1.043
		AEC	1.059	0.95	1.067	0.862	0.921	1.056	0.948
	CSEC		1.055	1.033	1.022	0.994	1.001	1.015	1.020
	CTC	*TC*	1.037	1.014	1.048	0.926	0.983	1.027	0.967
		IPE	0.965	0.995	0.956	1.102	1.009	0.972	1.044
Full private water companies	CGMPI		1.102	1.072	1.092	0.922	0.895	1.016	0.979
	CEC	*TEC*	0.971	1.026	0.972	1.009	1.065	0.998	1.014
		AEC	1.083	0.97	1.100	0.892	0.855	1.030	0.997
	CSEC		1.046	1.073	1.015	1.022	0.983	0.989	0.968
	CTC	*TC*	1.025	1.029	1.052	0.954	0.957	1.018	0.962
		IPE	0.978	0.974	0.956	1.050	1.045	0.983	1.040
Concessionary water companies	CGMPI		1.067	1.014	0.998	0.911	0.978	1.072	1.054
	CEC	*TEC*	0.971	1.082	0.939	1.095	0.991	0.955	1.073
		AEC	1.034	0.930	1.035	0.831	0.987	1.082	0.899
	CSEC		1.065	0.992	1.029	0.965	1.018	1.041	1.072
	CTC	*TC*	1.049	0.999	1.044	0.899	1.009	1.036	0.972
		IPE	0.952	1.016	0.956	1.155	0.974	0.961	1.049

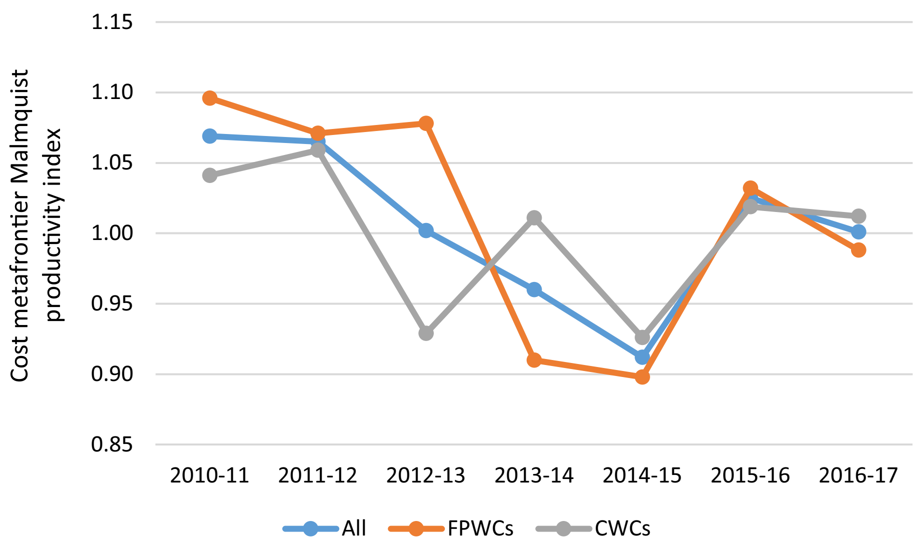

Fig. 2 Evolution of the cost meta-frontier Malmquist productivity index for each group of Chilean water companies

combination of their resources resulted in lower productivity (2.9% per year), on average. CTC fluctuated over the entire period, but improved productivity at a rate of 1% per year on average. Thus, average CWCs experienced technical progress within their group. This phenomenon was attributed to the combined effect of small improvements in technology and favourable input price effects, which reduced the cost of production. Overall, the results indicate that, when using the group frontier as a reference, the efficiency of less efficient FPWCs and CWCs improved toward the best water company, and moved closer to the optimal scale size. However, group-specific productivity could be further enhanced by improving resource allocation and adopting new technologies.

4.2 Cost Metafrontier Malmquist Productivity Index

Figure 2 presents the results from the estimation of the cost Malmquist productivity index over time using meta technology as a reference (CMMPI). This measurement was considered more appropriate compared to the group frontier results, as took group heterogeneities into account (Huang et al 2014; Cho 2018). A Mann–Whitney non-parametric test on the distribution of CMMPI showed a statistical difference in productivity between CWCs and FPWCs (p-value < 0.05). Figure 2 shows that, during 2010–17, the productivity of FPWCs and CWCs increased by 1.2% and 0.2% on average, respectively. Through using meta technology, the productivity of the water industry improved by 0.7% in 2010–17. The average productivity of FPWCs substantially increased during 2010–13, with an annual rate of 8%. However, productivity deteriorated in subsequent years, except for 2015–16. The productivity of CWCs was positive in most evaluated years. However, high negative rates of productivity were recorded during 2012–13 and 2014–15 (almost 7% per year on average), which offset any gains in productivity during the previous years.

Table 3 Decomposition of the cost meta-frontier Malmquist productivity index (CMMPI) and its drivers over time

	Productivity change and its drivers		2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
All water companies	CMMPI		1.069	1.065	1.002	0.96	0.912	1.025	1.001
	CEC	*TEC*	0.986	1.036	0.951	1.024	1.052	0.984	1.043
		AEC	1.044	0.965	1.052	0.921	0.863	1.049	0.973
	CSEC		1.034	1.06	0.997	1.014	1.001	0.993	0.979
	CTC	*TC*	1.009	0.986	1.029	0.99	0.977	1.011	0.984
		IPE	0.995	1.019	0.976	1.014	1.027	0.989	1.024
Full private water companies	CMMPI		1.096	1.071	1.078	0.91	0.898	1.032	0.988
	CEC	*TEC*	0.97	1.022	0.971	1.006	1.068	0.997	1.014
		AEC	1.075	0.971	1.088	0.892	0.851	1.037	1.003
	CSEC		1.046	1.073	1.015	1.01	0.984	0.994	0.969
	CTC	*TC*	1.017	0.992	1.018	0.999	0.97	1.003	0.994
		IPE	0.988	1.013	0.987	1.005	1.034	1.000	1.008
Concessionary water companies	CMMPI		1.041	1.059	0.929	1.011	0.926	1.019	1.012
	CEC	*TEC*	1.001	1.049	0.931	1.042	1.036	0.971	1.071
		AEC	1.014	0.959	1.017	0.95	0.875	1.06	0.942
	CSEC		1.022	1.047	0.979	1.019	1.018	0.993	0.989
	CTC	*TC*	1.001	0.98	1.039	0.98	0.983	1.019	0.974
		IPE	1.002	1.025	0.965	1.023	1.021	0.978	1.04

When considering the sources of productivity growth of FPWCs (Fig. S3 and Table 3), changes to CSE changes and small gains in TC and input price positively impacted productivity, whereas AEC and TC hindered productivity. TEC improved productivity during 2013–17, rising 2.1% annually on average. Consequently, less efficient FPWCs moved closer to the most efficient company in the entire industry. However, on average, these companies could not be considered as cost efficient, because they did not allocate resources, capital and operating expenditure well. CSE increased at an annual rate of 3.6% on average from 2010 to 2014, but considerably declined in subsequent years. Thus, while managers initially adjusted outputs and inputs in a way that allowed water companies to lower their cost of production, this adjustment was not beneficial for the last three periods of the study. Moreover, changes to the prices of resources favourably contributed to a reduction in cost production throughout the entire period. A beneficial IPE offset any losses in TC, contributing positively to CTC. FPWCs experienced stable, but small, technical progress during the evaluated period. Overall, FPWCs could further improve productivity by improving their managerial efficiency toward the most efficient company in the industry, and by adopting best technologies in the industry. FPWCs should also make better choices in terms of their resources, capital and operating expenditure, and in the combination of outputs, as this affects the scale of their operations and, thus, cost productivity.

The CMMPI results for CWCs indicated that changes to TEC and CSE were the major positive determinants of productivity growth, with an annual rate of increase of 1.5% and 1.0% on average, respectively. IPE also positively contributed to productivity over time, as it increased at an annual rate of 0.8% on average. Any gains in TEC, CSE and IPE were

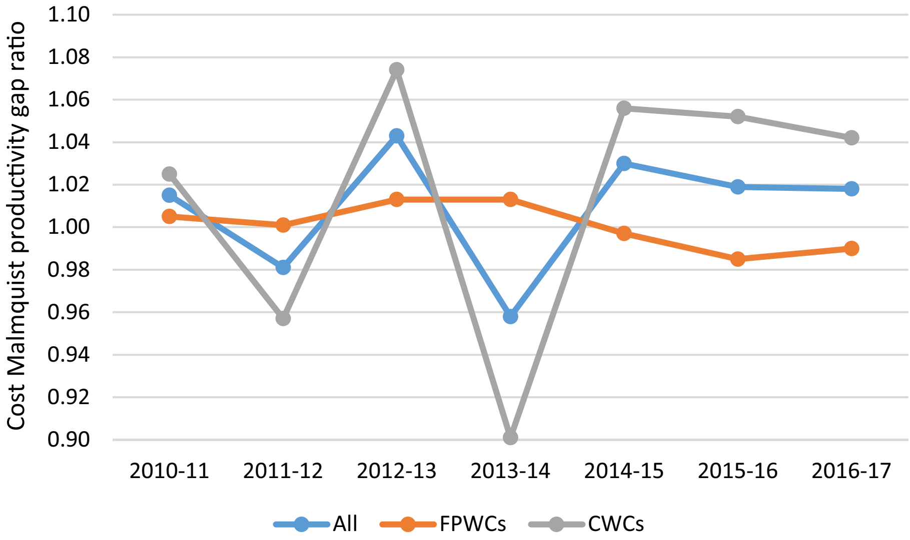

Fig. 3 Evolution of the cost Malmquist productivity gap ratio for each group of Chilean water companies

lost due to the inefficient cost allocation of resources and deterioration in technology. During 2013–14, less efficient CWCs reduced their daily management practices toward the most efficient water company in the industry, as technical efficiency gains increased at a rate of 3% per year. However, during that period, average CWCs reported high levels of cost inefficiency compared to the entire industry. These cost inefficiencies had a rate of 1.6% per year, and were attributed to inefficient cost allocation between capital and operating expenditure. Thus, while CWCs reduced all excess inputs (technical efficiency), they chose the wrong combination of inputs given input prices (allocative inefficiency).

Over the entire period, changes to the scale of operation of CWCs moved them closer to the meta optimal productive scale. However, in the last two time periods of the study, adjustments to the scale of operations based on the combination of inputs and outputs might not have been cost efficient. During 2010–17, CTCs slightly increased at 0.5% per year on average, which was attributed to the IPE. Changes in the price of network length and operating expenditure positively reduced cost in the production process. However, the low adoption of new meta technologies, which was apparent from 2013–14 onwards, hindered productivity. Overall, CWCs must show more leadership in adopting best technology practices, and must improve resource allocation to enhance the productivity of the entire industry.

4.3 Cost Malmquist Productivity Gap Ratio

The results of the cost Malmquist productivity gap ratio ($CMPI_G$) are shown in Fig. 3. Cost group-specific Malmquist productivity improved over the meta Malmquist productivity for both FPWCs and CWCs, as $CMPI_G$ exceeded 1. The rate of convergence in productivity between group and meta technology was 2% every year for CWCs. This value was considerably higher compared to that of FPWCs, which was 0.2% per year. For FPWCs, the productivity gap between group frontier and meta frontier declined from 2010 to 2014, but

Table 4 Decomposition of the cost Malmquist productivity gap ratio and its drivers over time

	Productivity change and its drivers		2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17
All water companies	$CMPI_G$		1.015	0.981	1.043	0.958	1.030	1.019	1.018
	CEGR	*TEGR*	0.985	1.018	1.005	1.027	0.977	0.992	1.001
		AEGR	1.014	0.984	1.014	0.935	1.067	1.007	0.975
	CSEGR		1.021	0.974	1.025	0.980	1.000	1.022	1.042
	CTCGR	*TCGR*	1.027	1.028	1.019	0.936	1.006	1.016	0.982
		IPEGR	0.969	0.977	0.980	1.087	0.982	0.983	1.020
Full private water companies	$CMPI_G$		1.005	1.001	1.013	1.013	0.997	0.985	0.990
	CEGR	*TEGR*	1.000	1.004	1.001	1.003	0.997	1.001	1.000
		AEGR	1.008	0.999	1.011	1.000	1.004	0.993	0.994
	CSEGR		1.000	1.000	1.000	1.013	1.000	0.995	0.999
	CTCGR	*TCGR*	1.007	1.038	1.033	0.954	0.986	1.014	0.967
		IPEGR	0.990	0.962	0.969	1.045	1.010	0.983	1.032
Concessionary water companies	$CMPI_G$		1.025	0.957	1.074	0.901	1.056	1.052	1.042
	CEGR	*TEGR*	0.970	1.032	1.009	1.051	0.956	0.983	1.001
		AEGR	1.020	0.970	1.018	0.875	1.128	1.021	0.954
	CSEGR		1.042	0.947	1.051	0.947	1.000	1.049	1.084
	CTCGR	*TCGR*	1.047	1.019	1.005	0.917	1.026	1.017	0.997
		IPEGR	0.950	0.991	0.991	1.129	0.954	0.983	1.008

increased from 2014. The rate of convergence in the productivity of CWCs considerably improved from 2014 onwards.

When considering the sources of the cost productivity gap ratio (Fig. S5 and Table 4), the technical efficiency, allocative efficiency, scale efficiency and technology of the FPWC group slightly converged, or remained constant, with those of the meta-frontier, and had a rate of 0.1% per year. In contrast, the price effect under the group frontier was slightly behind that of the metafrontier (by 0.1% per year). During 2015–17, allocative efficiency, scale efficiency and technology diverged at an annual rate of 0.7%, 0.3% and 0.9% on average, respectively.

The productivity gap ratio (Fig. S6) of CWC sources, adjustment to the optimal scale increased by 1.5%, speed of technological developments increased by 0.4% and input price effect slightly increased by 0.1%. In contrast, the technical efficiency of the CWC group remained unchanged with respect to that of the meta frontier. In particular, during 2014–17, there was a 1.2% average divergence per year in technical efficiency between group and meta frontier. The ability of the companies to catch up their allocative efficiency declined by 0.3% per year on average. Significant drivers of group production cost converging with meta production included the input price effect and, possibly, allocative efficiency and technical change for FPWCs, and allocative efficiency and technical efficiency change for CWCs (Table 4).

5 Conclusions

The water industry consists of several heterogeneous companies that operate with different production technologies. Thus, when conducting efficiency and productivity analysis, it is important to employ a productivity index that takes group heterogeneities into account. This study applied the cost Malmquist productivity index, using group and meta technology as benchmarks for a sample of fully private and concessionary water companies in Chile during 2010–17. We compared the results on changes to productivity between the cost group frontier and meta-frontier, and identified the drivers of productivity change. The rate of productivity convergence and divergence between group and meta technologies was assessed.

The empirical application of this approach showed that both FPWCs and CWCs had positive cost Malmquist productivity growth when using meta technology as a reference. FPWCs appeared to perform better than CWCs. The positive growth of FPWCs was attributed to adjustments in the scale of operations, technical efficiency change and input price effect. This result was also obtained for group technology. The positive determinants of productivity change for CWCs were derived from gains in technical and scale efficiencies, and favourable input price effects. Both FPWCs and CWCs could improve efficiency and productivity by moving to a cost-efficient allocation of resources and by adopting the best technologies of the industry.

Cost group frontier Malmquist productivity improved over cost meta-frontier productivity for both FPWCs and CWCs. The rate of productivity convergence was higher for CWCs compared to FPWCs. The sources of productivity convergence for FPWCs were mainly the ability of a company to catch-up in cost and scale efficiency. For CWCs, convergence was driven by the ability of companies to catch-up in scale efficiency and cost technical change. Thus, convergence between group and meta production cost could be achieved by improving the input price effect and, possibly, allocative efficiency and technical change for FPWCs. In the case of CWCs, this could be accomplished by increasing allocative efficiency and technical efficiency.

This study revealed several interesting implications for policy. The methodology used allows regulated companies and regulators to evaluate changes in productivity when group heterogeneities exist. Managers can identify what enhances or hinders productivity over time relative to specific groups and the entire industry. For instance, companies might have reduced excess amounts of inputs, but not have chosen the appropriate combination of inputs to be cost efficient. Companies can also determine whether their group-specific performance was able to catch up to the entire industry performance, and identify sources of productivity convergence or divergence between their own group and the entire industry. Our findings are expected to help managers to improve their understanding of what drives productivity, and identify strategies that could be adopted to enhance productivity.

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Authors Contributions AM: Conceptualization; data curation; validation; writing-original draft; methodology; software.

RSG: Methodology; software; writing-review & editing.

MMA: Methodology; software; writing-review & editing.

MMS: Project administration; resources; writing-review & editing; Formal analysis.

Data Availability The datasets generated and/or analysed during the current study are not publicly available due they were developed from primary sources of data but are available from the corresponding author on reasonable request.

Declarations

Ethical Approval This manuscript has been developed in compliance with Ethical Standards.

Competing Interests The authors declare that they have no competing interests.

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Authors and Affiliations

Alexandros Maziotis[1,2] · Ramon Sala-Garrido[3] · Manuel Mocholi-Arce[3] · Maria Molinos-Senante[1,4]

[1] Departamento de Ingeniería Hidráulica Y Ambiental, Pontificia Universidad Católica de Chile, Avda. Vicuña Mackenna, 4860 Santiago, Chile

[2] Department of Business, New York College, Av. Vasilissis Amalias 38, 105 58, Athens, Greece

[3] Departamento de Matemáticas Para La Economía Y La Empresa, Universidad de Valencia, Avd. Tarongers S/N5, Valencia, Spain

[4] Centro de Investigación Para la Gestión Integrada Del Riesgo de Desastres (CIGIDEN), ANID/FONDAP/15110017, Av. Vicuña Mackenna 4860, Santiago, Chile