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RESEARCH ARTICLE

Assessing productivity changes in water companies: a comparison of the Luenberger and Luenberger-Hicks-Moorsteen productivity indicators

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ABSTRACT
Interest in evaluating productivity changes in water companies has increased in recent years. In this paper, for the first time, we employ the Luenberger-Hicks-Moorsteen Productivity Indicator (LHMPI) to evaluate productivity changes in a sample of Chilean water companies from 2010 to 2016. Productivity change estimations obtained by both the Luenberger Productivity Indicator (LPI) and the LHMPI are compared. Moreover, both indicators were computed assuming constant and variable returns to scale technologies. The LHMPI estimates illustrate that productivity in Chilean water companies has slightly improved over the period studied due to the positive trend of outputs, whereas the inputs negatively contributed to productivity changes. Results from the empirical analysis enabled us to verify that the LHMPI and LPI (and their drivers) are statistically different. This conclusion illustrates that water regulators need to pay attention to the indicators used when assessing productivity changes in water companies.

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Productivity change; Luenberger productivity indicator; Luenberger-Hicks-Moorsteen; water utilities; performance

1. Introduction

Improving the productivity of water companies is a desirable aim for both the water companies themselves and citizens. Productivity assessments are a major issue for water companies and water regulators when developing policies to ensure long-term sustainability in water companies and to protect customers' interests. Moreover, for water companies operating under price cap regulation, the estimation of productivity growth is essential when setting water tariffs (Maziotis et al. 2015). Taking the English and Welsh water industry privatisation as a paradigmatic example study, several studies have focused on analysing the impact of privatisation on the productivity of water companies (e.g. Saal and Parker 2001, 2004; Marques 2008). Other studies have evaluated the impact of different regulations on productivity changes in water companies (e.g. Bottasso and Conti 2009; Portela et al. 2011; De Witte and Marques 2012; Guerrini, Molinos-Senante, and Romano 2018).

Regardless of the purpose of the study, from a methodological point of view, two main approaches have been applied to evaluate productivity changes in water companies: i) index numbers and ii) distance functions. The first approach depends on the input and output quantities and prices in order to assess productivity change (Diewert and Nakamura 2003). By contrast, the distance function approach does not require data on costs, input prices or output prices; rather, it facilitates the analysis of the drivers of productivity change, including various decompositions (Suárez-Varela et al. 2017). In the framework of the water industry, most empirical applications have adopted the distance function approach since their objective was to evaluate productivity changes in terms of the quantity of inputs used and outputs produced and not the profits of the water companies (Worthington 2014). Distance functions can be estimated using both parametric and non-parametric methods. While both techniques have strengths and weaknesses, in the framework of the water industry, most of the studies have employed data envelopment analysis (DEA), a non-parametric method that provides a convenient way of describing multi-input and multi-output production technologies without having to specify functional forms of the production frontier (Cooper, Seiford, and Tone 2007).

Several indexes exist to compute productivity changes in decision-making units (DMUs) (water companies). The Malmquist Productivity Index (MPI) is the most widely used index in the context of evaluating productivity changes in DMUs (Wang and Lan 2011). It is either based upon the Shephard input or the output distance function compatible with the DMU objectives of input minimisation or output maximisation (Färe, Grosskopf, and Lee 1995). This means that the analyst must choose to adopt either an output- or input-oriented approach; this is a major limitation of the MPI. Moreover, it is a ratio-based productivity index and therefore, it fails to identify whether any of the variables are equal or close to zero (Balk et al. 2008).

To overcome such limitations, Chambers, Chung, and Färe (1996) introduced the Luenberger Productivity Indicator (LPI) which employs the directional distance function to estimate productivity changes in DMUs. The directional distance function is a generalisation of the Shephard distance function and is a dual to the profit function (Chambers, Chung, and Färe 1998).

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Supplementary data can be accessed here.

The LPI is consistent with both output and input-oriented perspectives and therefore, it is a generalisation of, and superior to, the MPI (Boussemart et al. 2003). However, the LPI is not 'additively complete', i.e. it is not a ratio of an output aggregator to an input aggregator (O'Donnell 2012). As a result, the LPI cannot be separated into component (inputs and outputs) growth.

Briec and Kerstens (2004) proposed the alternative Luenberger-Hicks-Moorsteen Productivity Indicator (LHMPI) which is a profitability indicator that does not have a specific orientation. It is a difference-based, additively complete alternative to the ratio-based, multiplicatively complete Hicks-Moorsteen index (Briec, Kerstens, and Peypoch 2012). Because the LHMPI is additively complete, it allows the identification of the exact contributions of output and input changes to productivity. Briec and Kerstens (2004) provided the necessary and sufficient conditions to obtain equality between the LHMPI and LPI. In particular, they coincide under two demanding properties: i) inverse translation homotheticity of technology and ii) graph translation homotheticity. However, Briec and Kerstens (2004) concluded that these properties are strong and unlikely to be met in empirical work. Therefore, one expects that LHMPI and LPI to differ empirically.

Though not as popular as the MPI, the LPI has recently been used as a tool for empirical analysis. In the framework of the water industry, Molinos-Senante, Maziotis, and Sala-Garrido (2014) compared productivity growth values produced by both the MPI and LPI for a sample of English and Welsh water companies from 2001 to 2008. To evaluate the impact of the privatisation of water companies in Chile and compare the performance of fully private and concessionary water companies, Molinos-Senante and Sala-Garrido (2015) estimated the LPI of a sample of Chilean water companies for the period 1997–2013. Recently, Guerrini, Molinos-Senante, and Romano (2018) analysed the impact of regulatory reforms in Italian water utilities by evaluating and comparing productivity growth before and after the changes; in doing so, they estimated the LPI for 136 water utilities.

Notwithstanding the attractive properties of the LHMPI, only a few empirical studies can be found in the literature that have employed this indicator to evaluate productivity changes across topics such as pensions funds (Barros et al. 2008a); insurance companies (Barros, Ibiwoye, and Managi 2008b), forestry units (Managi 2010) and agriculture units (Ang and Kerstens, 2017; Kerstens, Shen, and Van de Woestyne 2018). However, the authors are not aware of any published paper on water companies' productivity assessments adopting the LHMPI and comparing it with the LPI.

To overcome this gap in the literature, this paper is concerned with the assessment of productivity changes in water companies whilst employing the LHMPI. The objectives of this paper are threefold. The first is to contrast the results of productivity change and its drivers using both the LPI and LHMPI. The second objective is to evaluate the productivity change and its drivers, namely the technical change (TC) and efficiency change (EC) of a sample of water companies. The third objective is to analyse the contribution of outputs and inputs to productivity growth; this can be performed because the LHMPI is an additively complete indicator. This supports decisions to improve the productivity of water companies in subsequent years because it allows variables to be identified and improved. The Chilean water industry was selected as the case study since water companies involved them are homogeneous in the sense that they are regulated under the same model, most of them (22 out of 23) are private and provide both water and sewerage services. Hence, it is a good example for benchmarking.

In this study, Section 2 describes the LPI and LHMPI methods applied to compute productivity change. Section 3 presents the data and variables used in this study. The results of applying LPI and LHMPI are presented and discussed in Section 4. The final Section 5 concludes the study.

2. Methodology

Productivity changes in water companies have been evaluated using two independent measures, namely: i) LPI and ii) LHMPI, which are subsequently described.

Both the LPI and LHMPI are non-parametric frontier technology approaches which employ the directional distance function to compute the productivity indicators; both are a flexible tool capable of taking into account both input contractions and output improvements when measuring efficiency (Luenberger 1992). Hence, we first define the directional distance function. Assuming that water companies use N number of inputs (x) to produce M number of outputs (y), the production possibility set for each time period t is defined as follows (Färe and Grosskopf 2000):

$$T(t) = \left\{(x^t, y^t) \in \eta_+^{N+M}; x^t can\ producey^t\right\} \quad (1)$$

The directional distance function $D_t(.,.;g) : \eta_+^{N+M} \to \eta$ in the direction of a pre-assigned vector $\vec{g^t} = \left(\vec{g_x^t}, \vec{g_y^t}\right) \in \eta_+^{N+M}$ is defined as (Chambers, Chung, and Färe 1996):

$$D_t\left(x, y; g_x^t, g_y^t\right) = max\left\{\theta; \left(x - \theta g_x^t,\ y + \theta g_y^t\right) \in T(t)\right\} \quad (2)$$

The directional distance function measures the gap between the observed production and the production frontier defined by the best units. θ is the inefficiency score and represents the maximum possible simultaneous decreases in inputs and increases in outputs.

2.1 The Luenberger productivity indicator

To avoid an arbitrary choice of base years, the LPI proposed by Chambers, Chung, and Färe (1996) is constructed as the arithmetic mean of the productivity change in the base year t and $t+1$ and is defined as follows:

$$\begin{aligned} LPI_{(t,t+1)(x^t,y^t,x^{(t+1)},y^{(t+1)};g^t,g^{(t+1)})} = {} & 1/2[(D_t(x^t, y^t; g^t) \\ & - D_t(x^{(t+1)}, y^{(t+1)}; g^{(t+1)})) \\ & + (D_{(t+1)}(x^t, y^t; g^t) \\ & - D_{(t+1)}(x^{(t+1)}, y^{(t+1)}; g^{(t+1)})] \\ & \equiv EC?_{(t,t+1)} + TC?_{(t,t+1)} \end{aligned} \quad (3)$$

The LPI can be separated into its EC and TC components where EC represents the catching-up of the water company and TC the change of production technology. An improvement in the EC implies that the DMU (in this study, the water company,) has moved closed to the efficient frontier in the period considered. Thus, EC is the capacity of the water companies to be managed in accordance with the best operational practices (Chen et al. 2018). The TC presents as a feasible input-output combination set which either expands or contracts. In other words, TC measures the shift of the efficient frontier between two periods (Ferreira and Marques 2016). In the water industry, effective long-term strategic planning and capital investment are essential factors to improving TC (Molinos-Senante, Maziotis, and Sala-Garrido 2014). The LPI and its components can be interpreted as follows: (i) an LPI > 0 means an improvement in productivity, (ii) an LPI < 0 means a worsening of productivity and (iii) an LPI = 0 means that the productivity has not changed (Molinos-Senante, Maziotis, and Sala-Garrido 2014).

2.2 The Luenberger-Hicks-Moorsteen productivity indicator

Chambers (2002) defined the output and input Luenberger productivity indicators between t and $t+1$, as follows:

$$LO_{t,t+1}\left(x^t, y^t, x^{t+1}, y^{t+1}; g_y^t, g_y^{t+1}\right) = \frac{1}{2}\left[LO_t + LO_{t+1}\right] \quad (4)$$

$$LI_{t,t+1}\left(x^t, y^t, x^{t+1}, y^{t+1}; g_x^t, g_x^{t+1}\right) = \frac{1}{2}\left[LI_t + LI_{t+1}\right] \quad (5)$$

where for the base period t:

$$\begin{aligned} LO_t\left(x^t, y^t, y^{t+1}; g_y^t, g_y^{t+1}\right) &= D_t\left(x^t, y^t; 0, g_y^t\right) \\ &\quad - D_t\left(x^t, y^{t+1}; 0, g_y^{t+1}\right) \end{aligned} \quad (6)$$

$$\begin{aligned} LI_t\left(x^t, x^{t+1}, y^t; g_x^t, g_x^{t+1}\right) &= D_t\left(x^t, y^t; g_x^t, 0\right) \\ &\quad - D_t\left(x^{t+1}, y^t; 0, g_x^{t+1}, 0\right) \end{aligned} \quad (7)$$

Similarly, for the base period $t+1$:

$$\begin{aligned} LO_{t+1}\left(x^{t+1}, y^{t+1}, y^t; g_y^t, g_y^{t+1}\right) &= D_{t+1}\left(x^{t+1}, y^t; 0, g_y^t\right) \\ &\quad - D_{t+1}\left(x^{t+1}, y^{t+1}; 0, g_y^{t+1}\right) \end{aligned} \quad (8)$$

$$\begin{aligned} LI_{t+1}\left(x^t, x^{t+1}, y^{t+1}; g_y^t, g_y^{t+1}\right) &= D_{t+1}\left(x^t, y^{t+1}; g_x^t, 0\right) \\ &\quad - D_{t+1}\left(x^{t+1}, y^{t+1}; g_x^{t+1}, 0\right) \end{aligned} \quad (9)$$

Briec and Kerstens (2004) defined the LHMPI with the base period t as the difference between a Luenberger output quantity indicator $LO_t\left(x^t, y^t, y^{t+1}; g_y^t, g_y^{t+1}\right)$ and a Luenberger input quantity indicator $LI_t\left(x^t, x^{t+1}, y^t; g_y^t, g_y^{t+1}\right)$:

$$\begin{aligned} &\mathrm{LHMPI}_t\left(x^{t+1}, y^{t+1}, x^t, y^t; g_y^t, g_y^{t+1}\right) \\ &= LO_t\left(x^t, y^t, y^{t+1}; g_y^t, g_y^{t+1}\right) - LI_t\left(x^t, x^{t+1}, y^t; g_y^t, g_y^{t+1}\right) \end{aligned} \quad (10)$$

The LHMPI with the base period $t+1$ is defined as:

$$\begin{aligned} &LHMPI_{(t+1)}\left(x^{(t+1)}, y^{(t+1)}, x^t, y^t; g_y^t, g_y^{(t+1)}\right) \\ &= ?LO?_{(t+1)}\left(x^{(t+1)}, y^{(t+1)}, y^t; g_y^t, g_y^{(t+1)}\right) \\ &- LI_{(t+1)}\left(x^t, x^{(t+1)}, y^{(t+1)}; g_y^t, g_y^{(t+1)}\right) \end{aligned} \quad (11)$$

To avoid an arbitrary choice of base periods, it is estimated the arithmetic average of $\mathrm{LHMPI}_{(t)}$ and $\mathrm{LHMPI}_{(t+1)}$ is as follows:

$$\begin{aligned} LHMPI_{(t,t+1)(x^t,y^t,x^{(t+1)},y^{(t+1)};g^t,g^{(t+1)})} &= 1/2\left[LHMPI_t + LHMPI_{(t+1)}\right] \\ &= 1/2\left[LO_t + LO_{(t+1)}\right] \\ &\quad - 1/2\left[LI_t + LI_{(t+1)}\right]LO_{(t,t+1)} \\ &\quad - ?LI?_{(t,t+1)} \end{aligned} \quad (12)$$

Equation (12) evidences that the LHMPI is the difference between an output indicator and input indicator, which themselves are arithmetic averages of two output and two input indicators. A LHMPI greater than zero indicates that productivity has increased, whereas a score less than zero means that productivity has decreased between time periods.

Similarly to the LPI, the LHMPI can be decomposed into EC and TC (Barros et al. 2008a):

$$\begin{aligned} TC_{(t,t+1)(x^t,y^t,x^{(t+1)},y^{(t+1)};g^t,g^{(t+1)})} &= \left[\left(D_{(t+1)}\left(x^{(t+1)}, y^{(t+1)}; g_x^{(t+1)}, 0\right)\right.\right. \\ &\quad \left. - D_t\left(x^{(t+1)}, y^{(t+1)}; g_x^{(t+1)}, 0\right)\right) \\ &\quad - \left(D_{(t+1)}\left(x^{(t+1)}, y^{(t+1)}; 0, g_{,y}^{(t+1)}\right)\right. \\ &\quad \left.\left. - D_t\left(x^{(t+1)}, y^{(t+1)}; ?0, g_{,y}^{(t+1)}\right)\right)\right] \end{aligned} \quad (13)$$

$$EC_{t,t+1} = LHMPI_{t,t+1} - TC_{t,t+1} \quad (14)$$

The estimation of the LPI requires the computation of four directional distance functions (see Equation (3)). By contrast, as shown in Equations (6–9), the LHMPI involves the computation of eight different directional distance functions. Following on from previous studies (e.g. Güngör-Demirci, Lee, and Keck 2018; Guerrini, Romano, and Indipendenza 2017; Worthington 2014), we used the DEA method to compute all the directional distance functions necessary to estimate both the LPI and LHMPI. It should be noted that the productivity change (LPI and LHMPI) and its drivers were estimated assuming both constant returns to scale (CRS) and variable returns to scale (VRS) technologies.[1]

3. Data and variables

The Chilean water companies are responsible for the overall urban water cycle, i.e. they provide both water supply and wastewater collection and treatment services. Most Chilean water companies are private as the water industry was privatised from 1998 to 2004. In fact, in 2016 private water companies provided water and sewerage services to approximately 96% of Chile's urban customers (SISS 2016). The sample used in this research consisted of 23 of the main Chilean water companies for the 2010–2016 period. These water companies provide both water and sewerage services to 95% of Chile's urban population (around 15,500,000 people) and operate throughout the country. The source of the statistical data was the management reports of the water and sewerage services which are annually published by the national urban water regulator: 'Superintendencia de Servicios Sanitarios'.

The objective of a water company is to carry out a productive process that supplies drinking water and collects and treats wastewater according to the quality standards defined by legislation at the lowest possible cost (Romano, Salvati, and Guerrini 2018). Thus, input and output variables to evaluate the productivity change of water companies were selected taking into account this premise, the available statistical data and past evidence (Berg and Marques 2011). In this context, three inputs were selected, namely: (i) operating costs, which is the total operating expenditure related to operating, maintaining and administering the urban water cycle (Carvalho and Marques 2016); this was expressed in Chilean pesos (CLP)[2] per year and was deflated using the consumer price index found in national statistics, (ii) labour, which involves the number of employees of the water companies and (iii) network length, which was used as a proxy for capital input (Ananda 2014). Taking into account the fact that the water companies evaluated provided both water and sewerage services, network length is the sum of the delivery and sewerage networks and was expressed in kilometres.

The outputs involved in the productivity change assessment must reflect the two services provided by the water companies analysed, i.e. water supply and sewerage services. Moreover, previous studies (e.g. Saal, Parker, and Weyman-Jones 2007; Kumar and Managi 2010; Guerrini, Romano, and Indipendenza 2017; Pinto, Simões, and Marques 2017) have evidenced that the quality of the services provided cannot be ignored in the performance assessment of water companies since they may incur non-negligible expenditures to improve the quality of the services provided (Ananda 2014). Thus, following Saal, Parker, and Weyman-Jones (2007) and Molinos-Senante, Donoso, and Sala-Garrido (2016), among others, two quality-adjusted outputs were selected to evaluate the productivity change in the water companies. The first output (y_1) refers to the volume of drinking water distributed (VDW) (expressed in thousands of cubic metres) adjusted by its quality (QDW) (Equation (14)). The second output (y_2) defined is the number of households with access to wastewater treatment services (CWW) multiplied by the quality of the wastewater treated (QWT) (Equation (15)). The QDW and QWT are two synthetic indicators developed by the Chilean water regulator for each water company and range between 0 and 1; a value of 1 means that the water company has fulfilled all legal standards related to drinking water and wastewater treatments. According to Equations (14) and (15), a value lower than 1 in the quality of service indicators (QDW and QWT) reduces the value of the output produced and therefore penalises the performance of the water company.

$$y_1 = VDW * QDW \tag{14}$$

$$y_2 = CWW * QWT \tag{15}$$

Table 1 provides a snapshot of the statistical data used to compute the LPI and LHMPI of the Chilean water companies evaluated from 2010 to 2016. It is clear that both the average input and output of the Chilean water companies increased between 2010 and 2016. In particular, the operating costs, adjusted to nominal costs by the Chilean Customer Price Indexes, rose by 36% during the period of study. The number of employees increased by 19%, whereas the network was lengthened by 3% from 2010 to 2016. The volume of water consumed per capita decreased between 2010 and 2016 (SISS 2016), but the total volume of drinking water distributed increased by an average of 14% as a result of population growth. From 2010 to 2016, the number of households with access to wastewater treatment services also notably improved (20.0%). The average value of the quality indexes for both drinking water and wastewater treatment services remained almost constant and close to one during the period of study.

Table 1. Sample description.

		INPUTS			OUTPUTS			
		Operating costs (CLP/year)[3]	Number of workers	Network length (Km)	Drinking water (10^3 m^3/year)	Quality of drinking water	People with access to wastewater treatment	Quality of wastewater treatment service
2010	Average	19,236,337	542	2,985	43,527	0.978	596,503	0.974
	Std. Dev.	27,699,458	723	4,769	86,827	0.041	1,050,706	0.047
2011	Average	[4]	539	3,040	44,942	0.966	593,894	0.956
	Std. Dev.	28,982,569	717	4,820	89,154	0.041	1,071,246	0.063
2012	Average	20,996,152	558	3,070	46,054	0.967	653,066	0.958
	Std. Dev.	29,173,451	735	4,863	89,905	0.053	1,251,561	0.056
2013	Average	22,807,929	576	3,110	47,096	0.974	670,944	0.965
	Std. Dev.	32,400,444	753	4,903	91,483	0.058	1,279,397	0.068
2014	Average	24,815,005	589	3,138	48,017	0.972	688,142	0.989
	Std. Dev.	34,759,245	766	4,941	93,059	0.043	1,314,547	0.015
2015	Average	26,119,220	610	3,180	48,747	0.982	704,389	0.971
	Std. Dev.	36,142,451	770	4,971	93,765	0.032	1,348,082	0.043
2016	Average	26,241,375	642	3,075	49,712	0.976	718,741	0.963
	Std. Dev.	35,823,639	793	4,650	95,175	0.062	1,387,790	0.045

Source: Own elaboration from national urban water regulator data

4. Results and discussion

4.1 Productivity change at water industry level

Productivity change was evaluated by computing the LPI and LHMPI and their drivers, i.e. the TC and EC from 2010 to 2016 assuming both CRS and VRS technologies. Figure 1 shows the average productivity change; the TC and EC of the 23 water companies were obtained for the two approaches assuming CRS technology. It can be seen that the productivity of the Chilean water companies only decreased between 2010 and 2011, whereas it improved throughout the remaining period. When comparing the LPI and LHMPI, Figure 1 shows that in all the years evaluated, the LPI values are smaller than the LHMPI ones. Moreover, with the exception of the period 2014/15, both the LHMPI and LPI approaches exhibited similar trends (productivity improvement or deterioration) for every year analysed. However, these small divergences involve that for the whole period of study (2010–2016), LPI and LHMPI estimates are opposite. Thus, according to the LHMPI productivity improved (LHMPI = 0.138) whereas according to LPI it slightly decreased (LPI = −0.037). Regarding the TC driver, i.e. the shift of the efficient frontier between periods, the LHMPI estimations reveal that the TC presented positive and negative values in alternative years; thus, there was an improvement of the TC in 2010/11, 2012/13 and 2014/15, whereas in the remaining years the TC negatively contributed to productivity changes in the water companies. By contrast, when the TC was computed using the LPI, it exhibited negative values for all years with the exception of 2012/13. This finding suggests that under the LPI approach, the TC negatively contributed to productivity change for nearly every year evaluated. The average accumulative TC for the 23 water companies evaluated was −0.034 and −0.060 for the LHMPI and LPI estimates, respectively. This means that in spite of the differences observed when the TC is analysed year by year, for the whole period of study (2010/2016) it can be concluded that the TC negatively contributed to the productivity growth of the Chilean water industry.

Figure 1 shows that under both approaches (LHMPI and LPI) for the period 2010/11, the EC was negative; this was the main contributor to the productivity retardation of the water companies. In subsequent years, the EC estimated using the LHMPI was positive, i.e. on average, the performance of the water companies moved closer to the efficient frontier. As in the case of productivity change values, the LPI's EC estimates exhibited lower values and were negative between 2012 and 2015. The accumulative values of the EC from 2010 to 2016 were positive for both the LHMPI (EC = 0.173) and LPI (EC = 0.023); it can therefore be concluded that, on average, the catching-up index positively contributed to the productivity growth of Chilean water companies.

Our results, based on the LPI, are consistent with those estimated by previous studies, although differences in the specific values of the productivity change and its components are observed. According to Molinos-Senante and Sala-Garrido (2015), the average LPI in the Chilean water industry from 2010 to 2013 was −0.017 and the main contributor to this retardation was the TC, whose value was −0.004; the EC, on the other hand, was positive (EC = 0.014). However, in their empirical application, the quality of the services provided by the water companies, i.e. the QDW and QWT, was not integrated in the productivity change assessment. These results evidenced that the quality of service provided by the water companies affects productivity change estimates. Recently, Molinos-Senante, Porcher, and Maziotis (2018) reported that from 2007 to 2015 the productivity of the Chilean water industry worsened, on average, by 7.93%; the culprits were the TC and EC by −9.5% and 0.48%, respectively. It should be noted that these authors applied a stochastic frontier analysis approach and integrated additional variables such as non-revenue water and customer density. Previous studies in other sectors such as agriculture (Odeck 2007) and transport (Cowie 2018) reported notable differences in productivity change values when they were computed using parametric and non-parametric methods.

As shown in Equation (12), the LHMPI is the difference between the Luenberger output quantity indicator and the Luenberger input quantity indicator. This means that it is possible to quantify the contribution of inputs and outputs to the productivity change of water companies. Figure 2 illustrates that, with the exception of 2015/16, inputs negatively

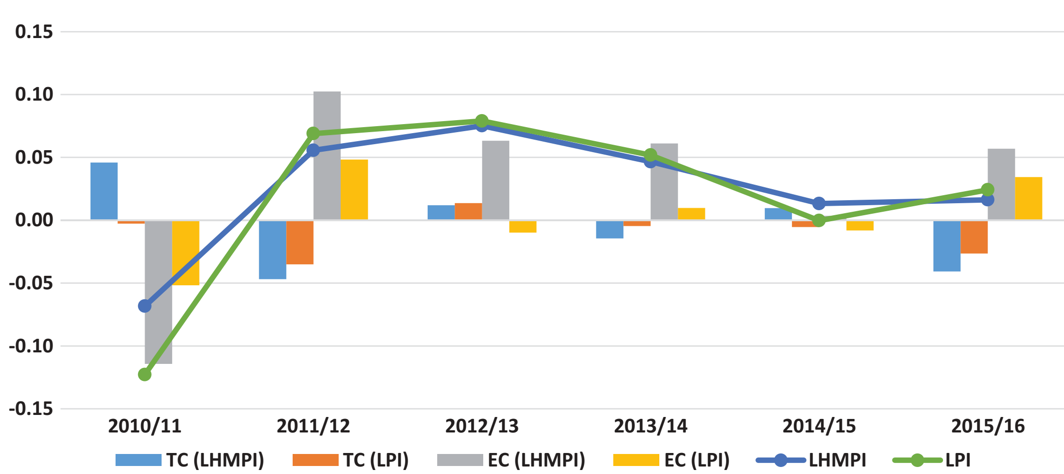

Figure 1. Average productivity change under constant returns to scale using Luenberger-Hicks-Moorsteen Productivity Indicator (LHMPI) and Luenberger Productivity Indicator (LPI) and its components, technical change (TC) and efficiency change (EC).

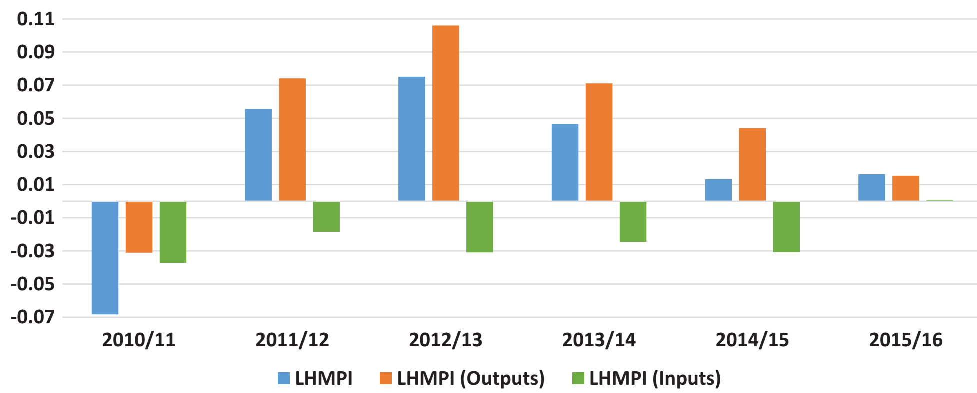

Figure 2. Contribution of outputs and inputs change to Luenberger-Hicks-Moorsteen Productivity Indicator (LHMPI) under constant returns to scale assumption.

contributed to the productivity change of water companies throughout the study period. The accumulative value of the Luenberger input indicator from 2010 to 2016 was −0.141, which means that during this period the Chilean water companies studied decreased their productivity in terms of operating costs and number of employees by 14.1%. This retardation in inputs use was almost constant throughout the study period; the Luenberger-Hicks-Moorsteen input indicators ranged between −0.037 and 0.0008. The Luenberger-Hicks-Moorsteen output indicator, in contrast, was positive during all the years studied, with the exception of 2010/11. This finding means that quality-adjusted outputs (water supplied and access to wastewater treatment as assessed by the quality of services) positively contributed to improving productivity in the companies studied. In fact, the accumulative value of the Luenberger output indicator between 2010 and 2016 was 0.279, i.e. the output change positively contributed to productivity growth by 27.9%. This positive trend counteracts the negative tendency of the input, resulting in an overall productivity increase for the Chilean water industry.

Figure 2 shows that 2010/2011 was the only period in which the productivity of the Chilean water industry declined, and it was due to both input and output contributions. It should be highlighted that on 27 February 2010, Chile suffered a severe earthquake (magnitude 8.8 Mw) which caused widespread damage on land and initiated a tsunami that devastated some coastal areas of the country. Together, the earthquake and tsunami were responsible for severe damage on the water supply and wastewater treatment. At national level, 35 drinking water treatment plants, 46 wastewater treatment plants and more than 100 water and wastewater networks systems were strongly affected (SISS 2010). This affection impacted negatively both on operational costs of water companies and its quality of service leading a notable retardation on the productivity of water companies. By contrast, from 2011 to 2015, Figure 2 shows that productivity improved thanks to the positive performance of outputs. By analysing the temporal evolution of the four variables embracing outputs (volume of drinking water, households with access to wastewater treatment, quality of drinking water and quality of wastewater treatment services) it is evidenced that the number of households with access to wastewater treatment is the variable that contributed the most to productivity improvement of Chilean water industry. By contrast, inputs which are strongly related to operational costs contributed negatively to productivity change. Thus, some cost items embracing operational costs such as energy costs or reagents costs increase across time above the customer price index and therefore, they negatively impact on the productivity of water companies. Finally, from 2015 to 2016, it is observed that both input and output remained almost constant which suggests that the Chilean water industry has reached a certain degree of maturity.

From a policy and managerial perspective, the results, as shown in Figure 2, provide evidence that in recent years the Chilean water companies analysed have focused on improving the quality of drinking water and sewerage services. This issue, coupled with the increase in population (17.0% for drinking water and 20% for wastewater treatment), has led to an improvement in productivity in terms of outputs generated. This improvement has not been associated with improved input performance. Previous studies (e.g. Carvalho and Marques 2011; Pinto, Simões, and Marques 2017) have evidenced that improvements in the quality of services usually implies an increase in operational costs, hence the relevance of considering quality-adjusted outputs in the productivity assessment rather than just quantity outputs.

As reported in the methodology section, both the LHMPI and LPI can be estimated assuming VRS technology. However, in certain cases the directional distance function is not well-defined and achieves a value of infinity (Chambers, Chung, and Färe 1996), leading to infeasibilities. The frequency of infeasible solutions depends, among others, on data structure, the specification of the technology and the choice of direction vector. Regardless, infeasibilities are not available under certain technology specifications (Briec and Kerstens 2009a). In spite of the fact that infeasibilities are a common problem in empirical applications, few studies explicitly report the prevalence of infeasibilities in productivity change estimates, partially due to ignorance on the side of the empirical researchers (Briec and Kerstens 2009b). However, according to Briec and Kerstens (2009a), in empirical applications estimating productivity change it is recommended that researchers simply report the infeasibilities that have occurred. In our empirical application, when LHMPI and LPI were computed assuming VRS technology, 15 out of 138 estimations were infeasible (10.9%). This percentage is similar to that reported by Glass and McKillop (2010), who reported infeasibilities of approximately 7%. Thus, productivity change values assuming VRS cannot be reported at water industry level (i.e. for all water companies evaluated); these are report in Section 4.2 alongside productivity change and its components.

4.2 Productivity change at water company level

Figure 1 shows that the productivity change and its drivers were variable throughout the study period. Furthermore, the evolution of productivity growth values and their components at water company level are discussed. Table 2 shows the accumulated values (from 2010 to 2016) of the productivity change and the EC and TC at water company level based on the LHMPI and LPI approaches, assuming VRS technology (results assuming CRS technology are provided as supplemental material). Although our study considered balanced panel data consisting of 23 water companies between 2010 and 2016, due to infeasibilities in the computation of the directional distance function, the accumulative values of productivity change are only reported for 19 water companies.

It can be seen that 10 out of 19 water companies (52.6%) suffered a retardation in productivity. In contrast, only five water companies (26.3%) exhibited a positive change in their productivity. This finding shows that four out of 19 water companies (21.1%) presented different results, i.e. positive and negative productivity changes when the LHMPI and LPI were applied. In particular, the productivity of all the water companies improved based on LHMPI estimates and worsened when LPI was used. For the TC component, both estimations (LHMPI and LPI) led to the same contribution (i.e. positive or negative values) for the 19 water companies. Thus, the TC negatively contributed to productivity change in the period of study in 11 of the 19 water companies (57.9%), whereas the shift of the efficient frontier was positive in the remaining eight water companies. Table 2 shows that based on both LHMPI and LPI, nine out of 19 water companies (47.4%) improved their catching-up index between 2010 and 2016. This means that they moved closer to the efficient frontier, thus positively contributing to productivity change. By contrast, seven water companies (36.8%) experienced the opposite, i.e. they suffered a retardation in their efficiency. The remaining three water companies (15.8%) experienced progress (EC>0) when the EC was estimated by applying the LHMPI and regressed (EC<0) based on LPI estimates.

Table 2. Accumulative values of productivity change under variable returns to scale using Luenberger-Hicks-Moorsteen productivity indicator (LHMPI) and Luenberger Productivity Indicator (LPI) and its components, technical change (TC) and efficiency change (EC).

	Productivity change		Technical change		Efficiency change	
Water company	LHMPI	LPI	TC (LHMPI)	TC (LPI)	EC (LHMPI)	EC (LPI)
2	0.254	0.022	−0.211	−0.083	0.465	0.105
3	−0.012	−0.030	0.057	0.000	−0.069	−0.030
4	0.045	0.029	−0.036	−0.135	0.080	0.165
5	−0.012	−0.085	−0.176	−0.143	0.165	0.058
6	−0.038	−0.063	0.019	0.052	−0.056	−0.115
7	0.649	0.390	0.080	0.251	0.569	0.139
8	−0.128	−0.195	−0.244	−0.210	0.116	0.015
9	−0.136	−0.234	−0.011	−0.187	−0.126	−0.047
10	0.147	0.097	0.017	0.020	0.130	0.077
11	0.032	−0.081	−0.034	−0.009	0.065	−0.072
12	0.834	−0.092	0.233	0.040	0.602	−0.132
16	−0.365	−0.201	−0.014	−0.150	−0.352	−0.051
17	0.041	−0.071	−0.088	−0.138	0.128	0.066
18	−0.352	−0.690	0.887	−0.128	−1.240	−0.561
19	0.081	0.024	−0.264	−0.161	0.345	0.185
20	−0.022	−0.009	0.025	0.024	−0.047	−0.033
21	0.062	−0.128	−0.109	−0.105	0.170	−0.023
22	−0.416	−0.618	0.167	0.000	−0.583	−0.618
23	−0.010	−0.010	−0.011	−0.079	0.000	0.069

Figure 3 shows the accumulative Luenberger input and output indicators between 2010 and 2016 for each water company evaluated assuming VRS technology. In other words, Figure 3 shows the contribution of inputs and outputs to productivity change in each water company from 2010 to 2016. Note that the values for the water companies numbered 1, 13, 14 and 15 are not provided because the estimation of the directional distance function was infeasible for these DMUs in some years. Most of the water companies analysed (17 out of 19) present the same trend regarding input and output changes, i.e. the contribution of inputs to productivity change was negative whereas the outputs exhibited a positive trend. The marked output improvement exhibited by water company 12 should be highlighted here; their quality-adjusted outputs increased by more than 100% from 2010 to 2016. The retardation of water company 18 in terms of their inputs used is similarly remarkable, since their outputs increased by 72.8% during the period of study. Water company 3 is the only one that displayed the opposite trend, i.e. outputs negatively contributed to productivity change while inputs positively contributed. However, the values of both the Luenberger input indicator and Luenberger output indicator were much closer to zero, leading to an LHMPI of −0.012. This result means that from 2010 to 2016 the productivity of water company 3 worsened by 1.2%. The other exception to the general trend is water company 16, for which both inputs and outputs negatively contributed to productivity. Based on these results, it is evidenced that most Chilean water companies should focus on reducing inputs to further improve their productivity. Nevertheless, assessing data at water company level allows the identification of specific variables (inputs or outputs) where each water company can act to improve its productivity.

The results shown in Table 2 illustrate that the largest differences between the LPI and LHMPI estimations were in the productivity change values, whereas the results for the TC and EC values are similar in both indicators. Because productivity change (LHMPI and LPI) is the addition of EC and TC, while general trends (positive and negative contributions) are similar between the two indicators, the specific values of each driver results in differences in the productivity change indicators. In order to test whether the differences in the productivity change and its components between the LHMPI and LPI estimations are statistically significant assuming both CRS and VRS technology, the non-parametric test of Mann-Whitney was carried out. The null hypothesis is that the LHMPI, EC and TC values from both indicators are not statistically different. Considering a 95% significance level, the null hypothesis can be rejected if the p-value is smaller than 0.05. Table 3 shows the p-values for each pair of years and for the whole period of

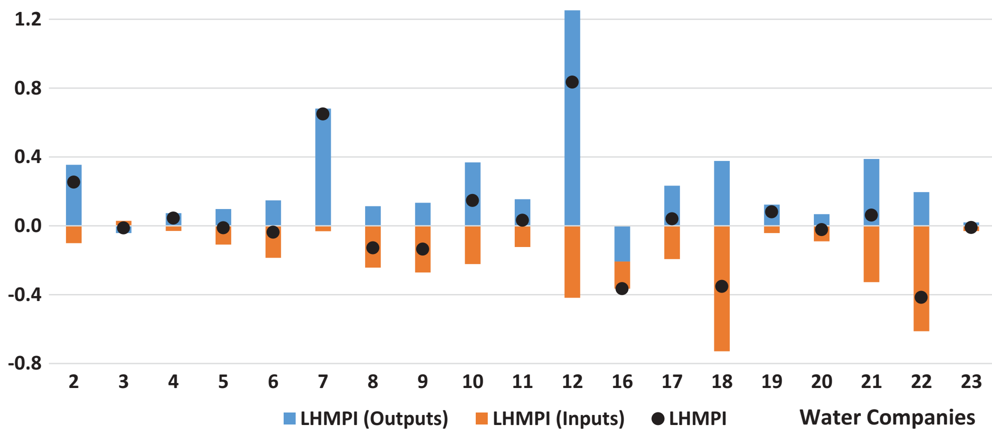

Figure 3. Contribution of outputs and inputs change to Luenberger-Hicks-Moorsteen Productivity Indicator (LHMPI) at water company level under variable returns to scale assumption from 2010 to 2016.

Table 3. p-values of Mann-Whitney test for comparing Luenberger-Hicks-Moorsteen and Luenberger Productivity Indicators and their components.

		2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2010/16
Constant returns to scale	Productivity change	0.801	0.503	0.022	0.244	0.386	0.404	0.502
	Technical change	0.007	0.423	0.568	0.701	0.084	0.267	0.362
	Efficiency change	0.047	0.767	0.001	0.150	0.560	0.102	0.055
Variable returns to scale	Productivity change	0.817	0.729	0.046	0.123	0.418	0.297	0.085
	Technical change	0.080	0.863	0.665	0.885	0.339	0.708	0.311
	Efficiency change	0.339	0.470	0.080	0.172	0.840	0.506	0.284

study for the productivity change values, EC and TC, based on the LHMPI and LPI; it is illustrated that the null hypothesis can be rejected in just five of 42 pair comparisons. These results indicate that productivity change and its components estimated using the LHMPI and LPI are statistically different under both CRS and VRS technology assumptions. This finding is consistent with the conclusions of Kerstens, Shen, and Van de Woestyne (2018), who reported that differences between the LHMPI and LPI estimations are significantly different for both technology specifications (CRS and VRS) and are most pronounced under a flexible returns to scale specification.

The differences between the LHMPI and LPI approaches suggest that policy-makers, water regulators and researchers should not be indifferent to the selection of a method for evaluating the productivity growth of water companies. This issue is even more relevant for water industries affected by price cap regulation since productivity growth estimates are used to set water tariffs.

5. Conclusions

The assessment of productivity growth over time and its drivers are of great importance to water regulators and water companies and so in recent years interest in evaluating this topic has increased. Many studies in the past have employed the Malmquist Productivity Index approach, whereas recent ones have employed the Luenberger Productivity Indicator. While the Luenberger Productivity Indicator is a generalisation of, and is superior to, the Malmquist Productivity Index, it is not additively complete. To overcome this limitation, this paper evaluates, for the first time, the productivity change of a sample of Chilean water companies applying the additively complete Luenberger-Hicks-Moorsteen Productivity Indicator, therefore allowing the identification and estimation of the inputs and outputs to productivity change. Moreover, the Luenberger and Luenberger-Hicks-Moorsteen Productivity Indicators are empirically compared to evidence the differences between the two indicators.

The primary findings of our study can be summarised as follows. First, at the water industry level, assuming constant returns to scale technology, the year on year assessment of the Luenberger and Luenberger-Hicks-Moorsteen Productivity Indicators of the general trends of productivity change are similar; however, the accumulative values for the period of study display the opposite results. When employing the Luenberger (Luenberger-Hicks-Moorsteen), productivity worsened (improved). Second, the decomposition of the Luenberger-Hicks-Moorsteen Productivity Indicator illustrates that, for most of the study period, inputs negatively contributed to productivity change whilst outputs positively contributed. It should be noted that quality-adjusted outputs were also considered to estimate the productivity growth of water companies, hence the positive trend of outputs may be due to both the increase in the quantity of outputs produced and their quality. Third, some infeasibilities are reported (11%) in the estimation of the directional distance function when variable returns to scale technology is assumed. This issue is consistent with theoretic, although most empirical studies have ignored them. Fourth, at water company level, assuming variable returns to scale technology and based on the Luenberger-Hicks-Moorsteen Productivity Indicator, half of the water companies evaluated improved their productivity between 2010 and 2016 thanks to the positive contributions of outputs. Finally, it is verified that differences between the Luenberger and Luenberger-Hicks-Moorsteen Productivity Indicators and their drivers (efficiency change and technical change) are significantly different for both the constant and variable returns to scale assumptions, but are most pronounced under the variable returns to scale technology specification.

From a policy perspective, our paper illustrates that water regulators need to pay attention to the indicator or index employed when assessing productivity changes in water companies. In particular, it has been confirmed that the Luenberger and Luenberger-Hicks-Moorsteen Productivity Indicators estimates are significantly different. Moreover, the decomposition of the productivity change into its output and input contributions allows water company managers to identify the main variables they should focus on in order to improve their company's productivity. From a regulatory point of view, the decomposition the productivity change into efficiency change and technical change acquires special attention since it enables water regulators to evaluate the innovative improvements (efficient frontier shift) of the water industry over time.

Notes

1. If output increases by the same proportional change as input changes then there are constant returns to scale (CRS). Variable returns to scale (VRS) exist when an increase in input does not result in a proportional change in output (see more details in Cooper, Seiford, and Tone 2007).
2. On 27 July 2018, 1 US$ = 642 CLP, 1 € = 748 CLP.
3. On 2nd April the currency rate was 742 CLP = 1 EURO.

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