

Assessing the Impact of Quality of Service on the Productivity of Water Industry: a Malmquist-Luenberger Approach for England and Wales

Alexandros Maziotis¹ · María Molinos-Senante^{2,3,4} · Ramon Sala-Garrido⁵

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Abstract Assessing productivity change over time and identifying its determinants is a valuable tool for water regulators when setting water tariffs. However, in a price cap regulatory framework such as in England and Wales policy makers should give attention to quality of service issues. Previous studies that assessed the productivity change of the English and Welsh water industry did not include the lack of quality of service to customers as undesirable outputs. To overcome this limitation, and as a pioneering approach, we estimated the Malmquist-Luenberger Productivity Indicator and its components, efficiency and technical change, for the 10 water and sewerage companies and the 12 water only companies over the period 2001–2008. To explore the role of quality of service to customers on the productivity change over time, we contrasted our results with a conventional measure of productivity change namely the Luenberger productivity indicator. The findings suggest that from 2001 to 2004 water companies made significant efforts to improve the quality of the service provided to customers, whereas after 2005 companies' performance regarding customer services was considered as poor. Results excluding quality of service variables illustrated that productivity

✉ María Molinos-Senante
mmolinos@uc.cl

¹ Fondazione Eni Enrico Mattei, Isola di San Giorgio Maggiore 8, Venice, Italy

² Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna, 4860 Santiago, Chile

³ Facultad de Arquitectura e Instituto de Estudios Urbanos, Pontificia Universidad Católica de Chile, El Comendador, 1916 Santiago, Chile

⁴ Centro de Desarrollo Urbano Sustentable CONICYT/FONDAP/15110020, Av. Vicuña Mackenna, 4860 Santiago, Chile

⁵ Department of Mathematics for Economics, University of Valencia, Avda. Tarongers S/N, Valencia, Spain

declined during all years evaluated. However, when the quality of service was introduced in the assessment, productivity improved by 4.13 % from 2000 to 2004 whereas it declined by 16.96 % in the following years. From a policy perspective, water utility regulators need to pay attention to quality of service issues when assessing companies' performance and setting water tariffs under comparative yardstick regimes.

Keywords Malmquist-Luenberger productivity index · Water utilities · Undesirable outputs · Quality of service · Data envelopment analysis · Directional distance function

1 Introduction

Water industry is regulated in many countries such as England and Wales, Chile, Portugal, Colombia, etc. due to two main reasons: (i) the provision of water and sewerage services is done through monopoly regime and (ii) the existence of social externalities (Molinos-Senante et al. 2015). In this context, benchmarking tools have gained interest in recent years to assess the effectiveness of the reforms and to evaluate the performance of water companies. Thus, from utilities' managers and regulators perspective, the assessment of the efficiency and productivity change of water companies is very useful to identify the best operational practices and to reduce operational costs (Carvalho and Marques 2014). The importance of assessing the efficiency and productivity change of water industry is specially marked in regions and countries where the process to set water tariffs follows a yard-stick competition approach such as England and Wales (Saal et al. 2007).

On the one hand, efficiency assessment involves comparing firm (water company in our case study) performance with respect to its main competitors, i.e., it is a static assessment and therefore, it only informs about the performance of water companies at a given moment in time rather than incorporating changes that have occurred over a period of time (Epure et al. 2011; Hernández-Sancho et al. 2011). On the other hand, the assessment of the productivity change of water companies is a dynamic benchmarking procedure since it evaluates how the firms are doing over time (Epure et al. 2011). Hence, to analyse the impact of the privatization and regulation in the performance of water industry, previous studies have focused on evaluating the productivity change of water companies from several countries such as Chile (Molinos-Senante and Sala-Garrido 2015); Portugal (e.g. Marques 2008; Da Cruz et al. 2012); Italy (Guerrini et al. 2013); Australia (Worthington 2014); England and Wales (e.g. Saal and Parker 2001; Erbetta and Cave 2007; Portela et al. 2011; Molinos-Senante et al. 2014; Maziotis et al. 2015a, 2015b). It should be noted that the case of UK is paradigmatic since it was the first water industry fully privatized worldwide. Thus, after the privatization of the English and Welsh water industry in 1989, the 10 publicly owned Regional Water Authorities formed the water and sewerage companies (WaSCs), whereas the 33 Statutory Water Companies formed the water only companies (WoCs) (Bottasso and Conti 2009). Since monopoly power was present in this industry, the economic regulator, i.e. the Water Services Regulation Authority (Ofwat) was set up to regulate water tariffs for customers.

As the regulation of water companies consolidate and they make up an industry technologically mature, quality of service issues become more important in the assessment of the performance of water companies. For example, in Portugal in the framework of sunshine regulation, the Institute for the Regulation of Water and Solid Waste was created which has several responsibilities with regard to quality of service regulation (Marques and Simoes

2008). Previous studies evidenced that ignoring the quality of service in the assessment of the performance of the water companies favours “low-cost” but low-quality companies while the ones providing high-quality at expense of larger costs are penalised. Depending of the main objective of the study, previous papers have considered several variables to introduce quality of service in the evaluation of the performance of water companies such as service coverage, percentage of water receiving treatment, service continuity, water losses, unaccounted-for-water, water quality, among others (e.g. Picazo-Tadeo et al. 2008; Corton and Berg 2009; Kumar and Managi 2010; De Witte and Marques 2010; Mbuvi et al. 2012; Hernández-Sancho et al. 2012).

In spite of the importance of the integration of quality of service to customers in the assessment of the performance of water companies, to the best of our knowledge, only two recent papers (Molinos-Senante et al. 2015, 2016) introduced variables such as complaints, penalties, unplanned interruptions or properties below the reference level in the assessment of the performance of water companies. While these studies are valid and of great use, they focused on efficiency assessment of water companies, i.e. they do not incorporate the time component. Ignoring the evolution of the performance of the water companies over time is a significant limitation of these previous papers since efficiency assessment does not inform about how water companies have improved (or worsened) the quality of service to users over time or how this change has impacted on its productivity.

To overcome this gap in the literature, this paper is concerned with the productivity change of water companies introducing variables representing the lack of quality of service to customers. From a methodological point of view, the studies by Picazo-Tadeo et al. (2008); De Witte and Marques (2010); Hernández-Sancho et al. (2012); Molinos-Senante et al. (2015, 2016) illustrated that in the framework of water industry, variables representing the lack of quality can be introduced in the performance assessment as undesirable outputs. In this context, the Malmquist-Luenberger productivity index (MLPI) (Chung et al. 1997) allows computing the productivity change of decision making units (DMUs) by considering the inputs as well as the desirable and undesirable outputs. The MLPI has been used to evaluate the productivity change accounting for undesirable outputs in several topics such as airports (Yu et al. 2008); oil blocks (Barros and Antunes 2014); power industry (Arabi et al. 2014); wastewater treatment plants (Molinos-Senante et al. 2015c). To the best of our knowledge, only the paper by Ananda and Hampf (2015) applies the MLPI to urban water sector. Nevertheless, their study focused on the integration of greenhouse gas emissions as undesirable outputs in the assessment of the productivity change of water utilities rather than quality of service to customers as we did.

The main objective of this paper is to evaluate the effect of introducing the quality of service to customers into the productivity change of water companies. In doing so, we carried out an empirical application for the English and Welsh water industry over the period 2001–2008. We contrasted results obtained using conventional measurement of productivity change, i.e., excluding quality of service variables, with values from an alternative method that incorporates quality of service variables. To compute changes in the productivity of water companies excluding the quality of service to customers, the Luenberger productivity indicator (LPI) was applied while the assessment including these variables was based on the MLPI. The comparison of both approaches allowed us to explore which water companies have done more efforts to improve the quality of the service to the customers and its effects into productivity. This information is very relevant for both water companies and the water regulator when reviewing water prices. Since both the LPI as the MLPI can be decomposed into efficiency

change and technical change, the second objective of this paper is to investigate the main drivers of the productivity change of the English and Welsh water companies. It should be noted that in spite of the significant development of empirical studies assessing the productivity change of the English and Welsh water industry, none of them integrates the lack of quality of service to customers as undesirable outputs.

This manuscript contributes to the current stand of literature in two main aspects. First, it assesses, for the first time, the productivity change of a sample of water companies introducing the lack of quality of service to customers as undesirable outputs. Second, the values of the LPI and the MPLI are compared in order to evaluate the effect of considering the quality of service in the assessment of the productivity change of the water companies. The methodology and conclusions of this paper are of great interest for water company managers and water regulators. It illustrates the importance of incorporating the quality dimension in the benchmarking process. Otherwise, water companies providing better service to customers are penalised. This issue is fundamental to set water tariffs by the regulator during the regulatory cycle. Our findings are also essential to promote the improvement of the quality of service to customers and to prevent water companies from focusing their main managerial objective on minimizing their operational costs.

The paper unfolds as follows. Section 2 presents the methodology employed in this section. The first chapter describes the conventional methodology which excludes quality of service from the productivity assessment while the second chapter presents the methodology to compute the Malmquist-Luenberger productivity index which integrates quality of service variables. Section 3 presents the sample data used in the case study. Section 4 presents the main findings, followed by a discussion of these results in Section 5. The final section concludes.

2 Methodology

The assessment of the productivity change of English and Welsh water companies was based on data envelopment analysis (DEA) methodology. It is a mathematical programming technique that based on available data (multiple inputs and outputs) constructs the efficient production frontier (Molinos-Senante et al. 2015). DEA measures the relative distance from where an individual DMU is located to the estimated efficient frontier which provides a score of the relative inefficiency of the cited DMU with respect to the best practice (Sala-Garrido et al. 2012). On the other hand, parametric methods such as stochastic frontier analysis (SFA) can be also used to compute productivity growth of DMUs. Unlike DEA, the main advantage of SFA is that it accounts for the effects of noise in the data and outliers (Carvalho and Marques 2014). However, to construct the efficient production frontier specification of its functional form is needed. Because DEA can accommodate multiple inputs and outputs simultaneously without imposing a functional form to the efficient production frontier, it was employed in this study to compute productivity growth of water companies.

2.1 Luenberger Productivity Indicator

Several indexes can be used to compute the productivity growth of DMUs when undesirable outputs i.e. variables for the quality of service are excluded from the assessment. If prices are

not available, the most commonly applied index is the Malmquist Productivity Index (MPI) (O'Donnell 2014) while other indexes such as the Hicks-Moorsteen index and the Färe-Primont index can alternatively be employed. In the framework of the water industry, previous studies have applied the MPI (e.g. Portela et al. 2011; Hernández-Sancho et al. 2011; Ali and Klein 2014) However, the MPI has a not negligible drawback since it is based on the Shephard distance function and requires a choice between an output and an input orientation (Goncalves 2013). To overcome this limitation, Chambers et al. (1996) introduced the LPI as a generalization of the MPI. The LPI uses the directional distance function to compute the productivity growth of DMUs and therefore; it can account simultaneously for output expansion and input contraction. An additional positive feature of the LPI is that it comes closest to the total factor productivity change while the MPI presents an upwardly biased estimate (Boussemart et al. 2003). Moreover, quality of service variables can be included in productivity assessment by employing the quality-adjusted Malmquist productivity index (QMPI) developed by Färe et al. (1995). This methodology however assumes that quality attributes are multiplicatively separable from outputs and inputs and quality remains constant when inputs and outputs change. Other studies by Saal and Parker (2001) and Maziotis et al. (2015a) used Tornqvist and Fisher indices, respectively to measure productivity and price performance across firms and over time construct quality-adjusted indices of outputs. However, these approaches assume that the customers pay the same price regardless of the level of quality they receive. In doing so, outputs/output prices will be biased upwards/downwards, and therefore productivity (TFP) and total price performance (TPP) results as well.

Because of their favourable features, the LPI has been recently used to compute productivity growth in the water industry. Molinos-Senante et al. (2014) evaluated and compared the productivity change of the English and Welsh water companies using both the MPI and LPI. Subsequently, the LPI was computed for a sample of Chilean water companies to investigate the impact of two privatization approaches of changes in productivity (Molinos-Senante and Sala-Garrido 2015).

Given a vector of inputs $x \in \mathfrak{R}_+^N$ that produces a vector of outputs $y \in \mathfrak{R}_+^M$, the production set T is the set of all the input-output vectors such as:

$$T = \{(x, y) : x \text{ can produce } y\} \tag{1}$$

The directional distance function considering inputs and outputs (only desirable) is defined as:

$$D_t(x_t, y_t; g) = \begin{cases} \sup \left\{ \delta : (x_t - \delta h; y_t + \delta k) \in T_t \right\} & \text{if } (x_t - \delta h; y_t + \delta k) \in T_t, \delta \in \mathfrak{R} \\ -\infty & \text{otherwise} \end{cases} \tag{2}$$

This is the directional distance function in the direction $g = (h, k)$. Since the aim of the productive process is to minimize the use of inputs and maximize the generation of outputs, the direction $g = (1, -1)$ was considered.

The LPI proposed by Chambers et al. (1996) is constructed as the arithmetic mean of the productivity change at T_{t+1} and at T_t (Balk 2001). The LPI is defined as (Eq. 3):

$$LPI = (x_t, y_t, x_{t+1}, y_{t+1}) = \frac{1}{2} \left[\left(D_t(x_t, y_t; g) - D_t(x_{t+1}, y_{t+1}; g) \right) + \left(D_{t+1}(x_t, y_t; g) - D_{t+1}(x_{t+1}, y_{t+1}; g) \right) \right] \tag{3}$$

The LPI is additively decomposed into the Luenberger efficiency change (LECH) and the Luenberger technical change (LTCH) (Eq. 4):

$$LPI(x_t, y_t, x_{t+1}, y_{t+1}) = [D_t(x_t, y_t; g) - D_{t+1}(x_{t+1}, y_{t+1}; g)] + \frac{1}{2} [D_{t+1}(x_{t+1}, y_{t+1}; g) - D_t(x_{t+1}, y_{t+1}; g) + D_{t+1}(x_t, y_t; g) - D_t(x_t, y_t; g)] = LECH + LTCH \tag{4}$$

The LPI and its components are interpreted as follows: (i) an LPI > 0 means an improvement in the productivity; (ii) an LPI < 0 means worsening of the productivity; and (iii) an LPI = 0 means that the productivity has not changed.

2.2 Malmquist Luenberger Productivity Index

To integrate undesirable outputs in DEA methodology, three approaches can be followed (Molinos-Senante et al. 2015c). First, undesirable outputs are considered directly as inputs (Tyteca 1996). However, this approach is inconsistent with standard axioms of productivity theory and do not reflect the production process (Färe and Grosskopf 2004). Second, undesirable outputs are transformed by a monotone decreasing function, i.e., undesirable outputs are converted into their reciprocals (Seiford and Zhu 2005). Third, it is considered that the disposal of undesirable outputs is costly or restricted. It is known as weak disposability assumption and it means that the production entity (water company in our case study) has to undertake costs to reduce the generation of undesirable outputs (Zhou et al. 2014). In the framework of water services production, the weak disposability assumption is fulfilled since to improve quality of service some infrastructure improvements would be required which involves costs. Hence, this approach was used in this study.

As for the LPI, assuming a production process in which from an input vector $x \in \mathcal{R}_+^N$ it is obtained a vector of outputs that can be desirable $y \in \mathcal{R}_+^M$ and undesirable $b \in \mathcal{R}_+^H$ using the technology T . Thus, the production possibility set is as follows:

$$P(x) = \{(y, b) : x \text{ can produce } (y, b)\} \tag{5}$$

Formally, in addition to the assumptions of no free lunch, convexity of the output set and free disposability of inputs, the output reference set satisfies the following assumptions (Chung et al. 1997):

$$(y, b) \in P(x) \text{ and } (y', b) \leq (y, b) \text{ imply } (y', b) \in P(x) \tag{6}$$

$$(y, b) \in P(x) \text{ and } 0 \leq \theta \leq 1 \text{ imply } (\theta y, \theta b) \in P(x) \tag{7}$$

$$\text{if } (y, b) \in P(x) \text{ and } b = 0 \text{ then } y = 0 \tag{8}$$

Eq. (6) refers to strong disposability of desirable outputs. It means that if a quantity of a desirable output y can be produced using x inputs, any amount $y' \leq y$ can also be produced with x . Eq. (7) express the assumption of weak disposability of undesirable outputs, i.e., undesirable outputs cannot be freely disposed. It involves that undesirable outputs can be reduced if a reduction in desirable outputs takes place, given a fixed level of inputs. Finally, Eq. (8) indicates that desirable and undesirable outputs are jointly produced. In other words, the only way to stop the generation of undesirable outputs is by no producing desirable outputs.

The assessment of the productivity change based on the MLPI requires the computation of the directional distance function including undesirable outputs which is defined as follows:

$$\vec{D}_o(x, y, b; g) = \sup\{\beta : (y, b) + \beta g \in P(x)\} \tag{9}$$

where g is the vector of directions in which outputs are scaled, and $g = (g^y, -g^b)$, such that $g^y \in \mathfrak{N}_+^M$ and $g^b \in \mathfrak{N}_+^H$. In our case, $g = (1, -1)$; that is, the desirable outputs are increased and undesirable outputs are decreased.

The productivity change of a DMU (water company) is measured by the ratio of two directional distance functions using t and $t + 1$ technologies as references (Färe et al. 1994). Considering $t = 1, \dots, T$ time periods and $k = 1, \dots, K$ DMUs, the MLPI is defined as (Chung et al. 1997):

$$MLPI_i^{t+1} = \left[\frac{\left(1 + \vec{D}_0^t(x^t, y^t, b^t; g^t)\right)}{\left(1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\right)} * \frac{\left(1 + \vec{D}_0^{t+1}(x^t, y^t, b^t; g^t)\right)}{\left(1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\right)} \right]^{1/2} \tag{10}$$

As other productivity indexes such as LPI and MPI, the MLPI may be disintegrated into two components namely the efficiency change (MLECH) and the technical change (MLTCH). The main advantage of such decomposition is that the drivers that most contribute to the productivity change (positive or negative) of each DMU are identified. From a policy and managerial perspective, this information is fundamental to develop measures to increase the productivity of the DMUs. On the one hand, the MLECH is related to the capacity of the DMUs to be managed in accordance with the best operational practices. A positive behavior of the MLECH means that the DMUs have moved close to the efficient frontier in the time interval considered (Simoes and Marques 2012). Hence, the efficiency change is known as the catching-up index. On the other hand, the MLTCH measures the shift in the efficient frontier between two periods (Arabi et al. 2014). In general, effective long-term strategic planning and capital investment are essential factors to improve MLTCH. In the water industry, a significant driving force to increase market competition and therefore contributing to a positive shift of the efficient frontier are institutional and regulatory reforms (Molinos-Senante et al. 2014).

The decomposition of the MLPI into the MLECH and the MLTCH is as follows Eqs. (11 and 12):

$$MLECH_i^{t+1} = \frac{\left(1 + \vec{D}_0^t(x^t, y^t, b^t; g^t)\right)}{\left(1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\right)} \tag{11}$$

$$MTECH_i^{t+1} \left[\frac{\left(1 + \vec{D}_0^{t+1}(x^t, y^t, b^t; g^t)\right)}{\left(1 + \vec{D}_0^t(x^t, y^t, b^t; g^t)\right)} * \frac{\left(1 + \vec{D}_0^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\right)}{\left(1 + \vec{D}_0^t(x^{t+1}, y^{t+1}, b^{t+1}; g^{t+1})\right)} \right]^{1/2} \tag{12}$$

The MLPI and its components (MLECH and MLTCH) are interpreted as follows: (i) a MLPI >1 means an improvement in the productivity; (ii) a MLPI <1 means worsening of the productivity; and (iii) a MLPI =1 means that the productivity is unchanged.

Taken into account the definition of the MLPI (Eq. 10), to compute it, four linear-programming problems must be solved for each DMU. Two of them involve observations from the same period (Eq. 13 and 14) while the other two problems are mixed-period ones (Eq. 15 and 16):

$$\begin{aligned}
 \bar{D}_0^t(x_k^t, y_k^t, b_k^t; g_k^t) &= \text{Max } \beta \\
 \text{s.t. :} & \\
 \sum_{k=1}^K \lambda_k^t y_{km}^t &\geq (1 + \beta) y_{k\bar{m}}^t, \quad m = 1, 2, \dots, M \\
 \sum_{k=1}^K \lambda_k^t b_{ki}^t &= (1 - \beta) b_{k\bar{i}}^t, \quad i = 1, 2, \dots, I \\
 \sum_{k=1}^K \lambda_k^t x_{kn}^t &\leq x_{k\bar{n}}^t, \quad n = 1, 2, \dots, N \\
 \lambda_k^t &\geq 0, \quad k = 1, 2, \dots, M
 \end{aligned} \tag{13}$$

$$\begin{aligned}
 \bar{D}_0^{t+1}(x_{k\bar{E}}^{t+1}, y_{k\bar{E}}^{t+1}, b_{k\bar{E}}^{t+1}; g_{k\bar{E}}^{t+1}) &= \text{Max } \beta \\
 \text{s.t. :} & \\
 \sum_{k=1}^K \lambda_k^{t+1} y_{km}^{t+1} &\geq (1 + \beta) y_{k\bar{E}m}^{t+1}, \quad m = 1, 2, \dots, M \\
 \sum_{k=1}^K \lambda_k^{t+1} b_{ki}^{t+1} &= (1 - \beta) b_{k\bar{E}i}^{t+1}, \quad i = 1, 2, \dots, I \\
 \sum_{k=1}^K \lambda_k^{t+1} x_{kn}^{t+1} &\leq x_{k\bar{E}n}^{t+1}, \quad n = 1, 2, \dots, N \\
 \lambda_k^{t+1} &\geq 0, \quad k = 1, 2, \dots, K
 \end{aligned} \tag{14}$$

$$\begin{aligned}
 \bar{D}_0^{t+1}(x_{k\bar{E}}^t, y_{k\bar{E}}^t, b_{k\bar{E}}^t; g_{k\bar{E}}^t) &= \text{Max } \beta \\
 \text{s.t. :} & \\
 \sum_{k=1}^K \lambda_k^{t+1} y_{km}^{t+1} &\geq (1 + \beta) y_{k\bar{E}m}^t, \quad m = 1, 2, \dots, M \\
 \sum_{k=1}^K \lambda_k^{t+1} b_{ki}^{t+1} &= (1 - \beta) b_{k\bar{E}i}^t, \quad i = 1, 2, \dots, I \\
 \sum_{k=1}^K \lambda_k^{t+1} x_{kn}^{t+1} &\leq x_{k\bar{E}n}^t, \quad n = 1, 2, \dots, N \\
 \lambda_k^{t+1} &\geq 0, \quad k = 1, 2, \dots, K
 \end{aligned} \tag{15}$$

$$\begin{aligned}
 \bar{D}_0^t(x_{k\bar{E}}^{t+1}, y_{k\bar{E}}^{t+1}, b_{k\bar{E}}^{t+1}; g_{k\bar{E}}^{t+1}) &= \text{Max } \beta \\
 \text{s.t. :} & \\
 \sum_{k=1}^K \lambda_k^t y_{km}^t &\geq (1 + \beta) y_{k\bar{E}m}^{t+1}, \quad m = 1, 2, \dots, M \\
 \sum_{k=1}^K \lambda_k^t b_{ki}^t &= (1 - \beta) b_{k\bar{E}i}^{t+1}, \quad i = 1, 2, \dots, I \\
 \sum_{k=1}^K \lambda_k^t x_{kn}^t &\leq x_{k\bar{E}n}^{t+1}, \quad n = 1, 2, \dots, N \\
 \lambda_k^t &\geq 0, \quad k = 1, 2, \dots, K
 \end{aligned} \tag{16}$$

where N is the number of inputs employed, M is the number of outputs produced, I is the number of undesirable outputs, K is the number of DMUs and λ_k is a set of

intensity variables representing the weighting of each observed DMU k in the composition of the efficient frontier.

3 Data and Variables Specification

In this study, we calculated the productivity change of the 22 English and Welsh water companies providing drinking water services. Hence, our assessment involves the 10 WaSCs and the 12 WoCs. Nevertheless, our assessment focused only on the water supply service excluding the sewerage service from the analysis. The same approach was followed by Molinos-Senante et al. (2014); Maziotis et al. (2015a, 2015b) due to two main reasons: (i) Saal et al. (2007) demonstrated the presence of economies of scope between water and sewerage services in the UK water industry and Carvalho and Marques (2014) for the Portuguese water industry. Hence, it is unsuitable to consider that both types of water companies (WaSCs and WoCs) have the same production frontier; and (ii) the English and Welsh water industry regulator (Ofwat) analyses separately water and sewerage services assuming that they are fully separable.

Since this paper is an extension of the productivity change assessment and efficiency evaluation studies carried out by Molinos-Senante et al. (2014, 2016) respectively, we used the same database. It is a balanced panel of the 22 English and Welsh water companies observed over the period 2001–2008. We collected additionally data for the undesirable outputs for the same 22 water companies and for the same time period. The source of data comes from “*June Returns for the Water and Sewerage Industries in England and Wales*” and companies’ performance report on service delivery to customers which are available at Ofwat’s webpage. The report summarises companies’ performance (e.g. Ofwat 2008): (i) in delivering the broad range of services provided to consumers (measured using the overall performance assessment – OPA); (ii) against minimum service standards (called ‘DG’ or ‘levels of service’ indicators); (iii) in maintaining their assets for the long term and the investments they have made; and (iv) in managing water supplies, including dealing with issues such as leakage and flooding.

To evaluate the impact of the quality of service in the productivity change of water companies, the same database was used to estimate the LPI and MLPI. Undesirable outputs, as a proxy to the lack of quality of service, were incorporated in the MLPI assessment. The selection of the inputs and outputs (desirable and undesirable) is always a difficult task in DEA analysis since they should be representative of the productive process. Moreover, regarding the number of variables to be included in the DEA model, the “Cooper’s rule” must be met. It means that the number of water companies analysed must be: $n \geq \max \{m \cdot s, 3(m + s)\}$ (Cooper et al. 2007), where m is the number of inputs used in the DEA study and s is the number of outputs involved. In this paper, 5 outputs (including both desirable and undesirable outputs), 2 inputs and 22 DMUs are considered. Therefore, the “Cooper’s rule” is met.

A literature survey conducted by See (2015) suggested that capital costs, the number of employees and operating costs are the most frequent choices for input measures in the earlier empirical studies. While there are several alternative methods for estimating capital, in the framework of the English and Welsh water industry, previous studies (Saal and Parker 2001; Molinos-Senante et al. 2014; Molinos-Senante et al. 2016a; Molinos-Senante et al. 2016b and Maziotis et al. 2015a, 2015b) have proxied capital stock by Modern Equivalent Asset (MEA) current cost estimates of the replacement cost of the existing capital stock of each water

company. Given the periodic revisions of the companies' MEA values, we also calculated the MEA values for previous years based on net investment. The second input considered in this study was the operating costs which is the water total operating expenditure and therefore involves power costs, resource costs incurred to abstract and treat the water as necessary, distribution costs, and business activities costs related to headquarter activities. Both inputs are expressed in thousands of pounds at constant prices.

Water companies use capital stock and operational costs to distribute volume of delivered water. Hence, the water distributed expressed as millions of liters per day was selected as desirable output. It reflects the volume of water treated and put into the distribution network for delivery to customers. Hence, it does not consider system leakages. Moreover, the number of connected properties to the water network was also considered as a desirable output since it is a proxy for urbanization and size (Ofwat 2009).

Regarding the variables representing quality of service in the assessment of the efficiency and productivity change of water companies, as it was reported by Molinos-Senante et al. (2015, 2016), it depends on the maturity of the water industry evaluated. Hence, in developing countries, variables such as service coverage, service continuity and percentage of treated water are frequently used to evaluate the quality of service (e.g. Berg and Lin 2008; Corton and Berg 2009; Kumar and Managi 2010; Mbuvi et al. 2012). On the other hand, water losses (De Witte and Marques 2010; Hernández-Sancho et al. 2012), unaccounted for water (Picazo-Tadeo et al. 2008) and water quality (Saal et al. 2007) are introduced in the efficiency assessment to consider quality issues in developed countries. However, these latest variables focus on the technical management of the water company and they do not reflect the quality of water services either to customers or from a regulator perspective. In this context, recently, Molinos-Senante et al. (2015) has introduced the total value of the penalties and total number of complaints in the efficiency assessment of Chilean WaSCs as proxies to quality of service to customers.

Since this study is a dynamic extension of the study by Molinos-Senante et al. (2016) we used the same variables as undesirable outputs to introduce quality of service in the assessment of productivity change of water companies. Hence, the three undesirable outputs considered are: (i) total number of written complaints (b_1) which is a direct measure of the perception by customers of the offered quality of service; (ii) total number of more than 12 h and 24 h of unplanned interruptions (b_2) and; properties below the reference level at the end of year (b_3). Ofwat requires that water companies supply water constantly and at a pressure which will reach the upper floors of houses. Hence, the number of properties below the reference level at the end of year is an excellent quality of service variable.

It is not our intention here to discuss about the suitability of different variables to measure quality of service. Taking into account that the main aim of this paper is to assess the impact of quality of service on the productivity of the English and Welsh water industry, the total number of written complaints, total number of more than 12 h and 24 h of unplanned interruptions and properties below the reference level at the end of the year are a good proxy to service quality of water companies from customer point of view. Additional variables such as drinking water quality or main bursts might be included as variables representatives of the service quality. However, given the limited number of water companies in the sample, the introduction of more undesirable outputs is not feasible.

Table 1 lists the sample averages and standards deviations (Std. Dev.) of the outputs and inputs variables for the period 2001–2008. The time evolution of the variables evidences that from 2001 to 2008 operating costs increased by 28.4 % while capital stock by 5.2 %.

Regarding the desirable outputs, the number of connected properties remained almost constant while the volume of water distributed increased by 1.5 % from 2001 to 2008 although it is observed that in the first period (2001–2004) this variable increased while in the second period (2004–2008) the average volume of water supplied by connection declined. From 2001 to 2005, the number of written complaints remained almost constant, while the last three last years evaluated (2006–2008) they increased notably. Any trend is observable in the number of unplanned interruptions, while the number of properties below the reference level decreased by 82 % from 2001 to 2008.

4 Results

In this section, we report the results obtained using the LPI and MLPI models described in Section 2. Because the main aim of this paper was to evaluate the impact of quality of service to customers into the productivity change of water companies, results for MLPI were computed using Max-DEA software while, for comparative purposes, results for the LPI are from Molinos-Senante et al. (2014).

The results regarding productivity change are shown in Fig. 1 which illustrates the average values of the 22 water companies evaluated obtained for the two approaches, i.e. excluding quality of service variables (LPI) and integrating them in the assessment (MLPI).

As it has been reported in Section 2, when productivity change is evaluated by computing the LPI, a water company improves its productivity if LPI is larger than 0. On the other hand, when productivity change is computed by the MLPI, a water company increases its productivity if the MLPI is higher than 1. Hence, it is not possible to compare directly the results from LPI and MLPI. For this reason, Table 2 shows the productivity growth rates and its components (average values for the 22 water companies evaluated) as percentages for the two approaches, i.e.; without considering the lack of quality of service to customers (LPI) and introducing the lack of quality of service in the DEA model as undesirable outputs (MLPI).

Table 2 illustrates that based on LPI, the productivity of the English and Welsh water industry declined significantly during the period evaluated (2001–2008). Actually, productivity decreased during all periods analysed with 2006/2007 being the period with the worst performance since productivity decreased by 4.7 %. However, if we focus on the results obtained when the quality of the service was introduced in the evaluation of the productivity change, i.e., results based on the MLPI, different conclusions can be drawn from our assessment. It is illustrated that during the first period, from 2001 to 2004, on average, the productivity of the water companies increased. Hence, for this period, the difference between the LPI and the MLPI is very illustrative. This finding means that from 2001 to 2004 water companies made significant efforts to improve the quality of the service provided to customers. In the traditional assessment of the productivity change (LPI), these efforts are ignored since none of the outputs and inputs introduced in the DEA model refer to the quality of service to customers. In mature water industries such as the English and Welsh, improving the service provided to customers is one of the main challenges water companies face. Hence, it is essential to integrate quality issues in the assessment performance of water companies. This issue is especially relevant in regulated water industries where the process to set water tariffs is linked in some way to the productivity change of the water companies. Results from our empirical application highlight that omitting undesirable outputs (quality of service variables) bias the productivity change results for water companies and therefore, mistaken managerial

Table 1 Sample descriptive

		2001	2002	2003	2004	2005	2006	2007	2008	
INPUTS	Operating costs (£000's)	Mean	68.2	68.3	69.6	72.4	73.9	80.0	86.8	87.6
		Std. Dev.	67.4	67.5	69.1	72.2	73.3	83.8	92.6	90.6
DESIRABLE OUTPUTS	Capital Stock (£000's)	Mean	3869.0	3891.0	3922.4	3955.6	3984.8	4007.8	4035.1	4070.4
	Water distributed (10 ⁶ l/d)	Std. Dev.	3919.1	3938.8	3972.9	4017.1	4060.1	4090.3	4117.3	4152.8
UNDESIRABLE OUTPUTS	Connected properties (Nr)	Mean	681.4	696.6	699.7	711.7	699.0	697.3	681.5	670.7
	Written complaints (Nr)	Std. Dev.	716.2	739.3	751.4	763.2	748.3	748.3	725.4	706.5
UNDESIRABLE OUTPUTS	Unplanned interruptions (Nr)	Mean	1067.5	1075.2	1081.9	1089.1	1095.9	1103.9	1110.4	1110.0
	Properties below reference level (Nr)	Std. Dev.	1098.6	1106.3	1113.1	1119.3	1125.1	1133.0	1138.6	1127.1
UNDESIRABLE OUTPUTS	Unplanned interruptions (Nr)	Mean	6054.6	6379.9	6335.5	6471.7	6498.1	8446.9	11,200.7	12,408.9
	Properties below reference level (Nr)	Std. Dev.	8310.5	8822.2	8701.4	8424.3	9242.4	13,199.5	18,123.4	16,932.0
UNDESIRABLE OUTPUTS	Unplanned interruptions (Nr)	Mean	659.2	1473.0	511.9	2065.0	1489.8	1027.8	2239.5	2037.0
	Properties below reference level (Nr)	Std. Dev.	1690.5	4851.0	1016.4	8790.6	3841.4	1944.9	5538.0	19,378.2
UNDESIRABLE OUTPUTS	Properties below reference level (Nr)	Mean	1199.4	1084.7	717.8	457.1	337.5	278.5	248.2	219.3
		Std. Dev.	1654.8	1604.0	1169.9	574.2	497.8	344.9	310.7	344.5

Source: Own elaboration from Ofwat data.

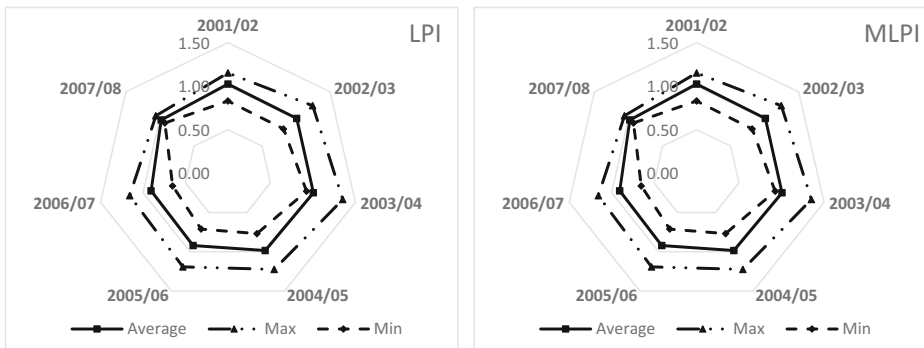


Fig. 1 Average, maximum and minimum values for the LPI and MLPI

and policy measures might be developed and implemented. During the second period evaluated (2004–2008) results from MLPI, as well as from LPI, evidence that productivity of the English and Welsh water industry decreased. However, annual growth rates differ considerably when productivity change was computed using the two alternative approaches. These results verify the importance of selecting an appropriate index to assess productivity change.

The trend of the factors driving productivity change confirms that from 2001 to 2004, water companies significantly increased the quality of their service to customers. Thus, during this first period, if we focus on Malmquist-Luenberger index, Table 2 shows that there was a positive shift of the efficient frontier of production. On the other hand, during the second period analysed (2004–2008) the average values of the MLTCH illustrate that the shift of the frontier was negative. Regarding the MLECH, no trend is observable since positive and negative values of the catching-up index are interspersed across the periods evaluated. This finding means that during some periods (2001/2002; 2003/2004 and 2004/2005) on average, water companies moved closer to the efficient production frontier, i.e. they improved their managerial practices. The assessment of the productivity change based on the MLPI, illustrates that the main driver of productivity growth of English and Welsh water companies when quality of service variables are considered was the technical change, i.e. the shift of the efficient frontier. On the contrary, the components of the LPI did not follow the same trend than the ones of the MLPI. Actually, the LECH and LTCH did not follow any trend but their contribution to the productivity change of the water companies was variable across years.¹

In order to further analyse the impact of introducing quality of service variables into the assessment of the productivity change, Fig. 2 illustrates the growth rate (%) of productivity based on the LPI and the MLPI for each of the 22 water companies evaluated for the period 2001–2008. Productivity change scores based on the LPI, i.e., excluding quality of service variables from the assessment, illustrates that from 2001 to 2008, 5 out of 22 the water companies (22.7 %) improved its productivity while the remaining 17 water companies (77.3 %) suffered a retardation of the productivity. Water companies numbered as 18 and 21 should be highlighted since they have the best and the worst performance, respectively. On the one hand, the water company 18 improved its productivity by 5.7 % and as it is shown in Figs. 3 and 4, the main driver of this improvement was the efficiency change. On the other

¹ The study by Molinos-Senante et al. (2014) provides additional information and details about the drivers of the productivity change when it is computed using the LPI.

Table 2 Average annual growth rates (%) for Luenberger productivity indicator and Malmquist-Luenberger productivity index

	Luenberger productivity indicator	Malmquist-Luenberger productivity index	Luenberger efficiency change	Malmquist-Luenberger efficiency change	Luenberger technical change	Malmquist-Luenberger technical change
2001/2002	-0.16	2.46	-1.34	1.77	1.17	0.75
2002/2003	-0.68	1.07	-0.45	-1.37	-0.23	2.40
2003/2004	-0.76	0.60	0.54	0.40	-1.30	0.24
2004/2005	-1.76	-1.52	-1.16	0.90	-0.60	-2.36
2005/2006	-2.46	-7.88	7.45	-0.07	-9.91	-7.52
2006/2007	-4.69	-5.60	-7.13	-1.54	2.44	-3.63
2007/2008	-0.94	-1.96	3.19	-3.53	-4.13	-3.53

Source: Own elaboration and Molinos-Senante et al. (2014)

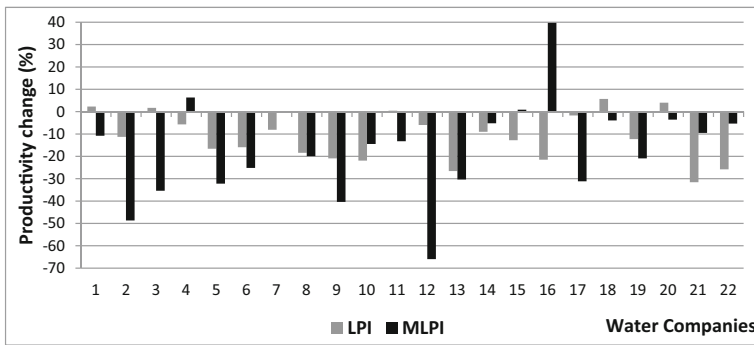


Fig. 2 Productivity growth rate (%) from 2001 to 2008 based on the Luenberger productivity index (LPI) and the Malmquist-Luenberger productivity index (MLPI) for the 22 English and Welsh water companies. Source: Own elaboration and Molinos-Senante et al. (2014)

hand, the water company 21 decreased its productivity from 2001 to 2008 by 31.6 % being the technical change the most important contributor to this decline.

When MLPI was used to compute the productivity change, i.e., when variables representative of the quality of service were introduced in the analysis, the productivity growth rate at water company level differs significantly from the alternative approach (LPI). Figure 2 illustrates that only 3 out of the 22 water companies (13.6 %) increased its productivity. It should be noted that these water companies are not the same with the ones which experimented a positive behaviour if quality of service variables are not considered in the assessment. An illustrative example of our approach can be seen in Fig. 2 where it highlights that the water company numbered as 16 showed a substantial improvement in its productivity (39.7 %). However, based on the LPI this water company suffered a retardation of its productivity (21.5 %). It means that this company did a significant effort to improve the quality of service to its customers. This water company is a clear example of how some water companies can be penalised in the assessment of its performance if quality of service variables are not considered in the analysis. By contrary, the water company numbered as 12 suffered a dramatic reduction in its productivity (66 %) during the period 2001–2008. However, following a traditional productivity assessment based on quantitative variables, this water company was favoured since according the LPI its productivity only declined by 6 %. The examples cited as the best

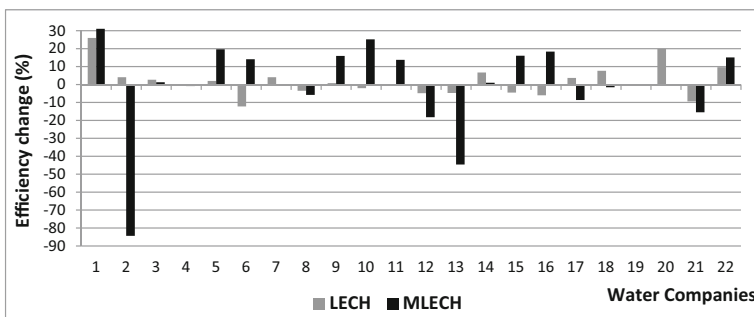


Fig. 3 Luenberger efficiency change (LECH) and Malmquist-Luenberger efficiency change (MLECH) growth rates (%) from 2001 to 2008 for the 22 English and Welsh water companies. Source: Own elaboration and Molinos-Senante et al. (2014)

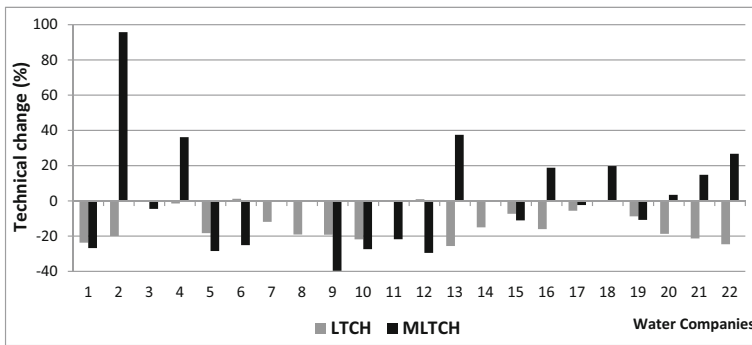


Fig. 4 Luenberger technical change (LTCH) and Malmquist-Luenberger technical change (MLTCH) growth rates (%) from 2001 to 2008 for the 22 English and Welsh water companies. Source: Own elaboration and Molinos-Senante et al. (2014)

and the worst cases have highlighted the importance of introducing quality of service variables in the assessment of the productivity of water companies.

Figures 3 and 4 provide some insights into the main factors driving productivity change for water companies in England and Wales. Regarding the catching-up index, Fig. 3 shows that based on LPI, half of the water companies evaluated moved away from the efficient frontier. In other words, they worsened their managerial practices. When quality of service variables are introduced in the assessment (MLECH) a slightly lower number of water companies (9 out of 22) decreased its efficiency. It should be noted that 7 water companies suffered a negative evolution of the efficiency under the two approaches, i.e. ignoring and introducing quality of service variables. While on average, the MLECH in the UK water industry from 2001 to 2008 remained almost constant (-0.35 %) there is one water company which highlights for its marked retardation in the catching-up index. That is the water company numbered as 2 since its MLECH retreated by 84.4 %. Although it is beyond the objectives of this paper, it would be very interesting to further study the circumstances that had led to this company to undergo this negative performance.

Regarding the technical change, as it has suspected when average values of the 22 water companies were analysed (Table 2), if quality of service is ignored from the assessment (LTCH), most of the water companies suffered a negative shift of the efficient production frontier. In particular, 19 out of the 22 water companies (86.4 %) experienced retardation in the technical change. This finding means that from 2001 to 2008 most of the English and Welsh water companies lost competitiveness since they needed more inputs to produce the same outputs (input orientation). This negative performance of the water companies is not as outstanding when quality of service is introduced in the assessment. Thus, the evaluation of

Table 3 Tests for statistical differences between LPI and MLPI and their components

Null hypothesis	Mann-Whitney U test		Kolmogorov-Smirnov Z test	
	p-value	Result	p-value	Result
LPI = MLPI	<0.001	Rejected	<0.001	Rejected
LECH = MLECH	<0.001	Rejected	<0.001	Rejected
LTCH = MLTCH	<0.001	Rejected	<0.001	Rejected

the technical change based on the MLPI indicates that only 11 out of the 22 water companies (50 %) had a negative shift of the efficient frontier. The remaining water companies whose MLTCH was positive are the ones which the most improved quality of service to customers.

To verify whether omitting quality of service to customers would result in biased estimates of productivity change and its components, the non-parametric tests of Mann-Whitney U and Kolmogorov-Smirnov Z were conducted. As it is shown in Table 3, the null hypothesis was that the LPI and the MLPI and their components had no significant difference. For the three hypothesis evaluated, the p -value for both non-parametric tests were lower than 0.05. This means that the three hypothesis are rejected and therefore, we concluded that the LPI and the MLPI and their components were statistically different at the 0.05 significance level. In other words, it was proved that the introduction of the quality of service to customers affects the score of productivity change of the English and Welsh water companies. This result is consistent with the study by Molinos-Senante et al. (2016) who concluded that efficiency scores of water companies (i.e. static assessment) differ significantly when quality of service variables are introduced in the analysis.

5 Discussion

Linking the results obtained from the MLPI with the regulatory cycle, it is concluded that when quality of service to customers is included in the analysis the overall performance of WaSCs and WoCs improved over the years 2001/02 to 2003/04 due to the 1999 price review when Ofwat imposed tougher X factors in the price cap formula, which might have provided strong incentives for water companies to improve efficiency and productivity. With the exception being the year 2002/2003, less efficient firms moved closer to the frontier whereas the benchmark firm continued to improve its productivity. This is attributed to the fact that after the 1999 price review, Ofwat introduced the Overall Performance Assessment (OPA), which is a composite measure of the WaSCs and WoCs levels of service, customer service and environmental performance. Ofwat's annual assessment includes a broad range of water and sewerage services such as water supply (water pressure, interruptions to supply); customer service (written complaints, compliant handling, billing contacts, meter reading); sewerage service (sewer flooding incidents and risk of flooding); environmental impact (leakage, pollution incidents from water and sewerage activities) (Ofwat 2003). Water companies that outperform against the above aspects of service are awarded in price limits whereas underperformance is penalised. During the years 2001/02 and 2004/05, it was reported that on average companies became more efficient and improved the levels of service to customers showing reductions in the number of properties at risk of low pressure and unplanned interruptions, whereas there was a slight increase in the number of written complaints (Ofwat 2004, 2005).

OPA was also employed in the 2004 price review. However, our findings suggest that during this period water companies did not improve their efficiency and productivity. This is attributed to dry winters in 2005/06 and severe flood in 2007 which had a negative impact on security of supply, i.e. unplanned interruptions (Ofwat 2006, 2008). Improving therefore customer service was considered of outmost significance for the water industry in the following years. The 2009 and 2014 price reviews replaced OPA with a new mechanism, the Service Incentive Mechanism (SIM) which provides a robust comparable measure of consumers' experience and how satisfied they are with the overall handling of an actual recent

contact with their water or sewerage supplier (Ofwat 2009, 2012, 2013). Moreover, Ofwat required each water company to set up a customer challenge group to ensure that the company's business plan reflects a sound understanding and reasonable balance of customers' views, and whether the phasing, scope and scale of work required to deliver outcomes – including legally prescribed standards and other regulators' requirements – is socially, economically and environmentally sustainable (Ofwat 2011). As a result, customers are also involved in the price review process. It has been recently reported that customers were increasingly satisfied with the manner in which their water company, both WaSCs and WoCs, resolves their queries (Magee and Counsell 2013; CCW 2014).

The differences observed in the productivity change of the water companies when the assessment introduces the quality of service to customers of when it ignores these variables has important repercussions from a policy perspective. Given that the process to set water tariffs in England and Wales depends on, among other factors, to the performance of the water companies, the omission of quality of service in the assessment of the productivity penalizes the water companies that provide better quality of service at the expense of larger operational costs. In the context of the English and Welsh water industry, the regulator follows a RPI + K price cap regime where K factor is composed by an efficiency factor, X, which is determined by comparing the performances of the water companies (i.e. by benchmarking) and by a Q factor to allow for the cost of meeting Drinking Water Inspectorate and Environment Agency mandated capital investment programs (Saal et al. 2007). Therefore, to promote the improvement of the service quality to customers in the English and Wales water sector, the X factor used to set the periodic growth rate of the water price for each company should be estimated by taking into account some service quality variables. This issue is fundamental to promote the improvement of the quality of service to customers. This issue is fundamental to promote the improvement of the quality of service to customers.

6 Conclusions

Assessing productivity change over time and identifying its determinants is a valuable tool for water regulators when setting water tariffs. However, in a price cap regulatory framework such as in England and Wales policy makers should give attention to quality of service issues. Otherwise, low-cost and low-quality companies will be labelled as “efficient” and therefore, water companies have not incentives to improve the quality of the service provided to customers.

Previous studies on assessing the productivity change of the English and Welsh water industry did not evaluate the impact of introducing quality of service to customers in the assessment. To overcome this limitation, and as an pioneering approach, we estimated the Malmquist-Luenberger Productivity Indicator (MPLI) for the 22 English and Welsh water companies over the period 2001–2008. The use of the MPLI allowed us to compute the productivity change of water companies over time by considering the inputs as well as the desirable and undesirable outputs (lack of quality of service) and identify the main driver of productivity change over time. To explore the role of quality of service to customers on the productivity change over time, we contrasted our results with a conventional measure of productivity change which does not integrate quality of service variables such as the Luenberger productivity indicator (LPI).

The primary findings of our study can be summarised as follows. Firstly, the LPI results suggest that water companies' productivity fell across all years of our study. However, it appears that the 2004 price review had an impact on the overall performance for both WaSCs and WoCs by stimulating less efficient firms to move closer to the frontier rather than encouraging best companies to continue to improve their performance. Secondly, the MPLI results reported that from 2001 to 2004 water companies made significant efforts to improve the quality of the service provided to customers whereas after 2005 companies' performance regarding customer services was considered as poor. Thirdly, an analysis at the company level allowed us to identify the primary driver of productivity change. That is the technical change, i.e. the shift of the efficient frontier when quality of service variables are considered. Finally, there were statistically significant differences between the water companies' productivity change over time when quality of service to customer was integrated in the analysis.

From a policy perspective, our paper illustrates that water utility regulators need to pay attention to quality of service issues when assessing companies' performance under comparative yardstick regimes. It was proved that the omission of quality of service in the assessment of the productivity penalizes the water companies that provide better quality of service at the expense of larger operational costs. Therefore, it is of outmost importance to include some quality of service variables in the price review process. This paper makes an original contribution to meeting this challenge by computing productivity growth for water companies with and without the inclusion of quality of service to customers.

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