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Accounting for service quality to customers in the efficiency of water companies: evidence from England and Wales

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Abstract

This paper investigates the role of service quality to customers in the efficiency assessment of water companies in England and Wales. To achieve this, data envelopment analysis techniques are employed to compute the technical efficiency of the water companies following two approaches: (i) traditional assessment based on quantity variables (without the inclusion of service quality variables) and (ii) alternative assessment considering quantity and service quality variables as undesirable outputs. The analysis covers 22 water and sewerage companies and water only companies providing drinking water services. The results indicate that the traditional efficiency assessment reveals a high level of technical efficiency, suggesting that the English and Welsh water industry is mature and that one of the challenges it faces is improving service quality. When introducing service quality variables in the evaluation, the average scores of technical efficiency slightly decrease. This suggests that, on average, water companies do not necessarily provide high quality of service, meaning that the traditional efficiency assessment favours their performance. Quality of service supplied to customers within a water sector matters and should be taken into account during the benchmarking process as it could assist regulated companies and regulators to improve performance and incentives, respectively.

Keywords: Data envelopment analysis (DEA); Efficiency; Performance; Undesirable outputs; Water utilities

1. Introduction

The assessment of relative efficiency of public and private water companies has proven to be a useful tool both for companies' managers and water authorities (Mansur & Olmstead, 2012). On the one hand,

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it enables the identification of the strengths and weaknesses of each water company and helps to save costs (Molinos-Senante *et al.*, 2013). On the other hand, and from a policy perspective, evaluating the water companies' performance enhances the design of public policies (Berg & Marques, 2011). Hence, performance assessment of water utilities has received much attention from policy makers, utility managers and researchers (Correira & Marques, 2011; Da Cruz *et al.*, 2012; Molinos-Senante *et al.*, 2015).

The importance of assessing the efficiency of the water industry is specially marked in England and Wales where it has come to be an important part of the process of determining the price of the water for urban uses (Cubbin, 2005). In this context, some empirical applications have mainly focused on analysing the impact of the privatization and regulation in productivity (or cost), price performance and/or profitability growth of the water industry (see, for instance, Ashton, 2000; Saal & Parker, 2000, 2001, 2004; Thanassoulis, 2000; Bottasso & Conti, 2003, 2009a, 2009b; Erbetta & Cave, 2007; Saal *et al.*, 2007; Maziotis *et al.*, 2009, 2012; Portela *et al.*, 2011).

In addition to traditional measures of technical efficiency, service quality is a performance indicator that warrants attention, since one important characteristic of water companies is that they must comply with quality standards (Parena *et al.*, 2002; Le Lannier, 2011). Ignoring service quality in the assessment of a water companies' efficiency penalizes companies that produce higher service quality since the 'low-cost' and low-quality companies are rated as efficient units (Picazo-Tadeo *et al.*, 2008; Kumar & Managi, 2010). In this context, Thanassoulis *et al.* (1995) and Lin (2005) pointed out that companies could have managerial problems when quality issues were considered as part of an analysis of organizational efficiency. For instance, a decision-making unit (DMU) might employ its inputs to improve service quality rather than increase its output and therefore can be considered as efficient regarding quality-related issues but inefficient regarding quantitative-related aspects (Schmenner, 1986). Moreover, a DMU might use its inputs to increase its outputs without giving any attention to service quality issues. Therefore, it might be considered as efficient in quantitative output but inefficient with respect to quality (Choi *et al.*, 2015).

In the English and Welsh context, Saal & Parker (2000, 2001) provide the first papers that started to underscore the importance of quality in assessing the performance of water utilities following the second approach, i.e., incorporating the quality dimension by using quality-adjusted indices of output. Because one of the motivations to privatize the English and Welsh water and sewerage industry was to provide environmental and drinking water quality regulation (Saal *et al.*, 2007; Maziotis *et al.*, 2014) previous studies dealing with the consideration of service quality in the performance assessment of the English and Welsh water companies are directly linked to environmental issues rather than service quality to customers (Saal & Parker, 2000, 2001; Saal *et al.*, 2007). However, in an industry which is technologically mature, as the English and Welsh water sector is (Ashton, 2000), measures based on both – the quantity and quality of the services supplied to customers – should play a critical role in the assessment of the water companies efficiency (Allan, 2006). It should be highlighted that in spite of the significant development of empirical studies dealing with the objective of assessing the efficiency and productivity of the English and Welsh water industry none of them introduce service quality to customers. In this sense, Section 3 provides further details about studies integrating service quality in the performance of water companies.

Previous studies that have considered the quality of service in measuring efficiency in water utilities follow three approaches: (i) introduce some variables representing quality together with other relevant variables in second-stage analyses to test for its influence on performance (e.g. Anwandter & Ozuna, 2002; Tupper & Resende, 2004; Berg & Lin, 2008; Mbuvi *et al.*, 2012); (ii) introduce quality-adjusted indices of outputs (e.g. Saal & Parker, 2001; Woodbury & Dollery, 2004; Saal *et al.*, 2007; Kumar & Managi, 2010); and (iii) introduce some variables representing lack of quality as undesirable outputs

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(Picazo-Tadeo *et al*., 2008; De Witte & Marques, 2010; Hernández-Sancho *et al*., 2012; Molinos-Senante *et al*., 2015). In this context, Saal & Parker (2001) employed an index-number approach to construct quality-adjusted indices of outputs by multiplying water and sewerage outputs with drinking water and sewerage treatment quality, respectively. Moreover, the study by Berg & Lin (2008) employed the quality-adjusted Malmquist productivity index to assess the impact of quality of service on the productivity change of water utilities in Peru. It was therefore assumed that quality attributes are multiplicatively separable from outputs and inputs, and that quality remains constant when inputs and outputs change. Recently, Lannier & Porcher (2014) employed a three-stage data envelopment analysis (DEA) approach to test the statistically significant impact of exogenous environmental variables on the efficiency of companies. While these studies are very useful and provide valuable findings, they do not focus on evaluating the impact of service quality to customers in the performance of water companies. The consideration of lack of service quality as undesirable outputs allows us to investigate the effect of introducing these variables in the assessment of the efficiency, since the quantity and quality-adjusted efficiency scores of the water companies can be compared directly.

Against this background, the main objective of this paper is to assess the efficiency of the English and Welsh water companies taking into account not just quantity but also service quality to customer variables. In a non-parametric DEA-based framework, total number of complaints, total number of unplanned interruptions and properties below the reference level are integrated into the model as undesirable outputs. To the best of our knowledge, only the studies by Picazo-Tadeo *et al*. (2008), De Witte & Marques (2010) and Hernández-Sancho *et al*. (2012) follow this approach to introduce quality issues into the assessment of efficiency. Unaccounted-for-water losses was the undesirable output introduced by Picazo-Tadeo *et al*. (2008), while De Witte & Marques (2010) and Hernández-Sancho *et al*. (2012) considered water losses to be the undesirable output in the assessment of the efficiency of water companies in Portugal and Spain, respectively. Hence, none of these three studies reflects the quality of water and sewerage services neither to customers nor from a regulator perspective. Recently, Molinos-Senante *et al*. (2015) introduced the total value of penalties and the total number of complaints in the assessment of the efficiency of Chilean water and sewerage companies (WaSCs). However, they did not explore the role of service quality to customers in the assessment of the efficiency of water companies, i.e. to determine whether the inclusion of quality of service affects benchmarking results or not. Thus, they did not compare quality-adjusted scores with scores from a conventional quantity evaluation. Hence, our paper contributes to the current strand of literature in the field of water utilities' performance measurement by computing scores of efficiency introducing variables representing service quality to customers as undesirable outputs.

From a policy perspective, the methodology and the conclusions of this study are of great interest for utility managers and regulators where price cap schemes are employed in conjunction with a system of yardstick or comparative competition (Le Lannier, 2011). For example, the Water Services Authority (Ofwat), which is the economic regulator of the water and sewerage companies in England and Wales, has been following a benchmark procedure for setting prices in the water and sewerage industry (Allan, 2006). However, Ofwat's benchmarking techniques and specifications of regulated inputs and outputs have been challenged by several studies such as the Cave (2009) review (Le Lannier, 2011). Moreover, great care must be taken to avoid unduly penalizing utilities (and managers) who seem to have high costs but provide higher levels of service quality (Lin, 2005). This was also emphasized by Giannakis *et al*. (2005) for the United Kingdom electricity distribution sector, who argued that cost-efficient firms do not necessarily exhibit high service quality: improvements in service quality have made a significant contribution to the sector's total productivity change and hence, the inclusion

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of quality of service in regulatory benchmarking techniques is important (Lin, 2005). Therefore, the implementation of a consistent methodology and the introduction of quantitative variables representing quality of service will improve the relevance of benchmarking tools, helping regulated companies and regulators to improve performance and incentives, respectively.

The paper unfolds as follows. Section 2 presents the methodology employed to assess the efficiency of water utilities, followed by a description of data in Section 3. Section 4 discusses the findings, while the final section concludes.

2. Methodology

There are two main approaches to measure the efficiency of decision-making units, namely parametric and non-parametric methods. Parametric methods, mainly stochastic frontier analysis (SFA), utilize econometric techniques since efficiency analysis relies on specified functional forms of production or cost functions. The main advantage of SFA is that it attempts to account for the effects of noise in the data (Berg & Lin, 2008). The non-parametric methods such as DEA use mathematical programming techniques and therefore, they do not require specification of production of cost functions, but develop a best practice frontier relating inputs to outputs (Charnes *et al*., 1978).

Both approaches have been widely used to assess the efficiency of water utilities under different contexts. In this sense, Berg & Lin (2008) evaluated the consistence of the performance ranking based on DEA and SFA methodologies for Peruvian water utilities. They concluded that both approaches yield similar rankings. Because DEA can easily accommodate multiple inputs and multiple outputs simultaneously without imposing weights to the factors, it was employed in this study. Nevertheless, it should be taken into account that DEA is sensitive to the selection of the variables for inputs and outputs, does not account for possible noise and is very sensitive to outliers (Cooper *et al*., 2007).

DEA is a mathematical programming technique that allows the construction of an efficient production frontier based on available data from the DMUs (water companies in our case) (Hernández-Sancho *et al*., 2011). DEA enables measurement of the relative distance from where an individual DMU is found to the estimated frontier. Therefore, it produces measurements of the relative inefficiency of the cited DMU when compared to what amounts to an industry best practice output/input ratio (Sala-Garrido *et al*., 2012). When a DMU obtains the maximum output given a vector of inputs (output-oriented DEA), or uses a minimum number of inputs (input-oriented DEA), it will be placed in the frontier of production and is, therefore, efficient. In the latter case, the technical efficiency of a production unit may be measured by calculating the maximum possible proportional to the reduction of factors used, consistent with their level of outputs (Charnes *et al*., 1996).

First, we will describe the methodological approach followed to assess the technical efficiency based on quantity variables – excluding service quality variables. A production process is assumed in which, from an input vector $x \in \Re_+^N$ we can obtain a vector of outputs $y \in \Re_+^M$ using the technology T. The production possibility set is the set of outputs that can be produced from a given level of inputs. The set is represented as (Equation (1)):

$$P(x) = \{(x, y) : x \text{ can produce } y\} \quad (1)$$

$P(x)$ is assumed to satisfy the usual axioms initially proposed by Shephard (1970) such as the

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possibility of inaction, no free lunch (zero inputs will produce zero outputs and, any non-negative inputs will produce at least zero output), convexity of the output set, free disposability of inputs (the same level of outputs can be produced always using higher quantities of inputs) and strong disposability of outputs (lower quantities of outputs can be produced at no cost using the same inputs) (Grosskopf, 1986).

The output distance function is defined as (Equation (2)):

$$D_o(x, y) = \min\left[\theta : \{y/\theta\} \in P(x)\right]. \tag{2}$$

The output distance function generalizes the production technology of a multi-output multi-input utility. It is non-decreasing and positively linearly homogeneous (Kumar & Managi, 2010). The output distance function represents the maximal radial expansion of specific outputs given existing resources (Mbuvi *et al.*, 2012). It takes a value which is less than or equal to 1.0 if the output vector is an element of the feasible production set. $D_o(x, y)$ will take a value of 1.0 if the output vector is located on the outer boundary of the production possibility set.

The computation of the output distance functions through DEA can be done imposing constant or variable returns to scale. Banker *et al.* (1984) extended the pioneering DEA model developed by Charnes *et al.* (1978) from a constant returns to scale to a variable returns to scale case by including an extra convexity restriction in the CCR model. Technical inefficiency under CCR is the product of scale inefficiency and pure technical inefficiency while the BCC model measures just technical inefficiency. Therefore, the BCC model is more relevant for analysing sectors such as water utilities where variable returns to scale is an important feature (Torres & Morrison Paul, 2006; Saal *et al.*, 2013). Moving on to Tupper & Resende (2004), Hernández-Sancho *et al.* (2012), Mbuvi *et al.* (2012), among others, the BCC model has been applied to measure technical efficiency. Secondly, a choice should be made between the use of an input-oriented or output-oriented DEA model. Both approaches have been used in previous studies measuring the efficiency of water utilities. The selection of the orientation depends mainly on the objective of the efficiency assessment. In our study, quality is incorporated as a relevant dimension of the production process. Moving to Picazo-Tadeo *et al.* (2008) and Hernández-Sancho *et al.* (2012), and taking into account that service quality to customers is introduced as undesirable outputs, it is considered that output orientation is more appropriate to deal with the objective of this study. Once the returns to scale and orientation are defined, technical efficiency for each DMU is computed as (Equation (3)):

$$\begin{aligned}
&D_{k'}(x_{k'}, y_{k'})^{-1} = Max\, \theta_{k'} \\
&s.t. \\
&\sum_{k=1}^{K} \lambda_k y_m^k \geq \theta_{k'} y_m^{k'} && m = 1, \ldots, M \\
&\sum_{k=1}^{K} \lambda_k x_n^k \leq x_n^{k'} && n = 1, \ldots, N \\
&\sum_{k=1}^{K} \lambda_k = 1 && k = 1, \ldots, K \\
&\lambda_k \geq 0 && k = 1, \ldots, K
\end{aligned} \tag{3}$$

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where $\theta_{k'}$ is a scalar variable that approximates the DMU's technical efficiency $\left(1/\theta_{k'}\right)$, M is the number of outputs produced, N is the number of inputs employed, K is the number of DMUs (water companies) and, λ_k is a set of intensity variables representing the weighting of each observed DMU k in the composition of the efficient frontier.

DEA research dealing with the introduction of service quality variables as undesirable outputs is presented below. To integrate undesirable outputs in DEA methodology, two approaches, namely indirect data transformation and direct approaches, can be followed (Hailu & Veeman, 2001). Indirect approaches transform the values of the undesirable variables by a monotone decreasing function and, therefore, they can be included in the model with the desirable outputs which are maximized. Hence, the original values are minimized (Lovell & Pastor, 1995; Scheel, 2001; Seiford & Zhu, 2002). Direct approaches modify and impose some assumptions of the model. Hence, the undesirable outputs can be included in the DEA model (Färe *et al.*, 1989; Chung *et al.*, 1997). In our case study, to introduce output quality in an efficiency assessment, two basic assumptions were made: first, according Picazo-Tadeo *et al.* (2008) and Hernández-Sancho *et al.* (2012), that the lack of service quality can be regarded as undesirable outputs; and second, that a trade-off between quantity and quality exists.

A production process is assumed in which, from an input vector $x \in \Re_+^N$ we can obtain a vector of desirable outputs $y \in \Re_+^M$ and another vector of undesirable outputs $z \in \Re_+^H$ using the technology T. In processes involving the generation of undesirable outputs, the production possibility set is represented as (Equation (4)):

$$P^u(x) = \{(y, b){:}x \,\text{can produce}\, (y, b)\}. \tag{4}$$

The notation $P^u(x)$ has been introduced to distinguish the production possibility set involving undesirable outputs from the one integrating just desirable outputs $P(x)$. In addition to the assumptions of no free lunch, convexity of the output set and free disposability of inputs, the technologies involving the generation of both desirable and undesirable outputs satisfy the following assumptions (Chung *et al.*, 1997). (i) Strong disposability of desirable outputs (Equation (5)). If a given quantity of a desirable output y can be produced from x, any amount $y' \leq y$, can also be produced with x. (ii) Weak disposability between desirable and undesirable outputs (Equation (6)). A reduction of undesirable outputs can only be feasible if a reduction in desirable outputs takes place, holding fixed the input level. In other words, the undesirable outputs cannot be freely disposed of because there is a cost involved with these outputs. (iii) Desirable and undesirable outputs are jointly produced (Equation (7)). The only way to avoid the production of undesirable outputs is by producing zero desirable outputs.

$$(y, b) \in P(x) \,\text{and}\, (y', b) \leq (y, b) \,\text{imply}\, (y', b) \in P(x) \tag{5}$$

$$(y, b) \in P(x) \,\text{and}\, 0 \leq \theta \leq 1 \,\text{imply}\, (\theta y, \theta b) \in P(x) \tag{6}$$

$$\text{if}\, (y, b) \in P(x) \,\text{and}\, b = 0 \,\text{then}\, y = 0. \tag{7}$$

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The output distance function including undesirable outputs is defined as follows (Equation (8)):

$$D_o(x, y, b) = \min \left[\sigma: \left(\frac{y}{\sigma}, b\right) \in P^u(x)\right]. \quad (8)$$

Following Färe *et al.* (1994a, 1994b), for each DMU k' an output distance function can be obtained by solving the following optimization problem using linear programming (Equation (9)):

$$\begin{array}{ll} D_{k'}(x_{k'}, y_{k'}, b_{k'})^{-1} = Max\, \sigma_{k'} & \\ s.t. & \\ \sum_{k=1}^{K} \lambda_k y_m^k \geq \sigma_{k'} y_m^{k'} & m = 1, \ldots, M \\ \sum_{k=1}^{K} \lambda_k x_n^k \leq x_n^{k'} & n = 1, \ldots, N \\ \sum_{k=1}^{K} \lambda_k b_h^k = b_n^{k'} & h = 1, \ldots, H \\ \sum_{k=1}^{K} \lambda_k = 1 & k = 1, \ldots, K \\ \lambda_k \geq 0 & k = 1, \ldots, K \end{array} \quad (9)$$

where $\sigma_{k'}$ is a scalar variable that approximates the DMU's technical efficiency $\left(1/\sigma_{k'}\right)$, M is the number of desirable outputs, N is the number of inputs employed, H is the number of undesirable outputs, K is the number of DMUs (water companies) and, λ_k is a set of intensity variables representing the weighting of each observed DMU k in the composition of the efficient frontier. Given a fixed quantity of inputs and the restrictions imposed by the available technology, the program (Equation (9)) searches for the maximum feasible expansion of outputs maintaining the level of undesirable outputs. Following the same approach as in Equation (3), variable returns to scale and output orientation are imposed in Equation (9).

3. Sample and data description

In England and Wales, there are two types of water companies, namely water and sewerage companies (WaSCs) and water only companies (WoCs). Most previous studies analysing the performance of the English and Welsh water sector have focused on the 10 WaSCs (Ashton, 2000; Saal & Parker, 2000, 2001; Erbetta & Cave, 2007; Saal *et al.*, 2007). The exceptions are Bottasso & Conti (2003), Saal & Parker (2006), Le Lannier (2011), and Portela *et al.* (2011) who assessed the water supply service of both WoCs and WaSCs, and Bottasso & Conti (2009a, 2009b) who evaluated the WoCs.

The assessment of the performance of the WaSCs in conjunction with the WoCs or in isolation is not a trivial issue because of the possible existence of economies of scope. Although there is considerable evidence regarding the existence of economies of scope between water production and distribution (Saal *et al.*, 2013), there is no consensus regarding the existence of economies of scope between water and sewerage services (Guerrini *et al.*, 2013). To examine the economics of scope, several methodological

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approaches can be used. Most studies are based on the approach introduced by Färe *et al*. (1994a, 1994b) which consists of estimating the frontier of multiproduct DMUs and the frontier of DMUs constructed from the sum of specialized DMUs. Using a shared input DEA methodology, Da Cruz *et al*. (2013) estimated not only the overall efficiency of water utilities, but also the efficiency in each of the services provided, i.e., drinking water and wastewater services. More recently, Carvalho & Marques (2014) used a partial frontier non-parametric methodology to search for scope economies in the Portuguese water sector. In particular, they used order-α and order-m methods which do not envelope all the observed data of the sample to estimate the production frontier.

In this study, we compute the technical efficiency of the 22 WaSCs and WoCs providing drinking water services in England and Wales focusing only on the water service and without considering the sewerage service. There are three main motivations to follow this approach. Firstly, Ofwat implicitly assumes that the water and sewerage operations of a WaSC are fully separable and, therefore, they analyse separately these two activities. Secondly, Saal & Parker (2006) concluded that it is inappropriate to consider that WaSCs and WoCs share the same production function because of the existence of economies of scope between water and sewerage services. The non-separability of water and sewerage operations within one company and possible cost interactions between these services must be borne in mind during the regulatory process (Walter *et al*., 2009). Finally, Portela *et al*. (2011) who estimated the productivity change of WaSCs and WoCs from 1993 to 2007 find significant differences in the productivity of both types of companies.

The data used in this study consist of a balanced panel of the 22 English and Welsh WaSCs and WoCs observed over the period 2001–2008. This period is selected in order to have balanced panel data since in 2000 the total number of WaSCs and WoCs was 26 and in 2009 it was 21 as a consequence of the merger between South East Water and Mid Kent Water (Portela *et al*., 2011). The source of data essentially comes from the '*June Returns for the Water and Sewerage Industries in England and Wales*' published by Ofwat each year on its webpage.

Selecting the output and input variables to be included in a DEA model is always a difficult decision. As Tupper & Resende (2004) pointed out, if a large set of variables is chosen, the relative efficiency discrimination across DMUs will tend to become blurred as there will exist some dimension in accordance with which a DMU will be deemed as efficient. In particular, a necessary assumption to apply DEA methodology is 'Cooper's rule' meaning that the number of DMUs 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, five outputs (including both desirable and undesirable outputs), two inputs and 22 DMUs are considered. Therefore, 'Cooper's rule' is met.

To evaluate how service quality affects water companies' performance, the same database is used to estimate the quantity and the quality-adjusted efficiency scores although undesirable outputs are introduced in the latter assessment. According to the objectives of the paper, the following variables are selected:

- Inputs: (i) capital stock (x_1) and (ii) operating cost (x_2). Following the approach of Saal & Parker (2001) and Maziotis *et al*. (2009, 2012), the capital stock is proxied by Modern Equivalent Asset (MEA) current cost estimates of the replacement cost of the firm's existing capital stock. We also systematically calculated the MEA values for previous years based on net investment, as is necessary given the periodic substantial revisions of the companies' MEA values. The operating cost is the water total operating expenditure which includes power costs, resources and treatment costs incurred

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in abstracting and treating the water as necessary, distribution costs incurred in supplying water from treatment to customers, and business activities costs relating to headquarter activities.

- Desirable outputs: (i) water distributed (y_1) and (ii) number of connected properties (y_2). Several papers highlight that improvement in assessing efficiency of water utilities can be accomplished if both the volume of water delivered and the number of connected properties are considered as outputs (Thanassoulis, 2000; García & Thomas, 2001). The variable water distributed reflects the quantity of water treated and put into the distribution network and, ideally, the variable to be integrated in the model should be the number of connected properties per km of main instead of the total number of connected properties. However, as a ratio variable, it should not be used together with volume measures in DEA assessment (Portela *et al*., 2011).
- Undesirable outputs: (i) total number of written complaints (b_1), (ii) total number of more than 12 hours and 24 hours of unplanned interruptions (b_2), and (iii) properties below the reference level at the end of year (b_3). The first variable (b_1), is a measure of the perception by customers of the offered service quality and, therefore, a small number of complaints indicates a higher quality of service (Corton & Berg, 2009). Variables b_2 and b_3 provide information about the reliability of the water distribution service and therefore also about the service quality to customers.

In the water industry, the variables representing service quality differ considerably from one country to another. On the one hand, in developing countries, service coverage, percentage of water receiving chemical treatment or service continuity are the most common used variables to measure service quality (Lin, 2005; Berg & Lin, 2008; Corton & Berg, 2009; Kumar & Managi, 2010; Mbuvi *et al*., 2012). On the other hand, in developed countries where water services cover nearly all the population, alternative measures of service quality are required (Tupper & Resende, 2004; Alegre *et al*., 2006). In previous studies, different variables have been used to measure quality in water utilities such as: water losses (Antonioli & Filippini, 2001; García & Thomas, 2001; Hernández-Sancho *et al*., 2012); unaccounted-for-water (Picazo-Tadeo *et al*., 2008); annual mains breakage per observed output (Bhattacharyya *et al*., 1994); water quality (Saal & Parker, 2000, 2001; Woodbury & Dollery, 2004; Erbetta & Cave, 2007; Bottasso & Conti, 2009a, 2009b); and bathing water intensity (Saal *et al*., 2007).

It is not our intention here to discuss the suitability of different variables to measure service quality. Taking into account that the main aim of this paper is to assess the efficiency of the English and Welsh water companies introducing service quality to customers, the variables of total number of written complaints, total number of more than 12 hours and 24 hours 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 the customer point of view. Additional variables such as water quality or main bursts might be included as variables representative of the service quality. However, given the limited number of DMUs in the sample, the introduction of more undesirable outputs is not feasible.

Descriptive statistics of our data are gathered in Table 1. For all of the variables the standard deviation (SD) is almost equal to the average, reflecting the fact that water companies differ much in scale size, especially so between WoCs and WaSCs. The time evolution of the variables illustrates that the capital stock increased by 5.2% while operating costs rose 28.4% from 2001 to 2008. Regarding the desirable outputs, the evolution of the volume of water distribution is interesting since it is shown that from 2001 to 2004 it increased but during the period 2004–2008 it decreased reaching a volume lower than that in 2001. Because this variable reflects the volume of water put into the distribution network (water leakages are not considered in this variable) and the number of connected properties increased in the

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Table 1. Sample descriptive.

	Capital stock (£000's)	Operating cost (£000's)	Water distributed (10^6 l/d)	Connected properties (Nr)	Written complaints (Nr)	Unplanned interruptions (Nr)	Properties below reference level (Nr)
2001							
Average	3,869.00	68.24	681.41	1,067.51	6,054.68	659.23	1,199.54
SD	3,919.12	67.45	716.26	1,098.56	8,310.50	1,690.53	1,654.87
2002							
Average	3,891.05	68.34	696.62	1,075.20	6,379.91	1,473.05	1,084.73
SD	3,938.85	67.52	739.38	1,106.32	8,822.25	4,851.08	1,604.01
2003							
Average	3,922.40	69.58	699.71	1,081.95	6,335.55	511.95	717.78
SD	3,972.93	69.09	751.40	1,113.16	8,701.42	1,016.39	1,169.89
2004							
Average	3,955.60	72.44	711.71	1,089.15	6,471.73	2,065.00	457.12
SD	4,017.08	72.18	763.22	1,119.31	8,424.32	8,790.56	574.21
2005							
Average	3,984.79	73.92	699.00	1,095.98	6,498.09	1,489.82	337.54
SD	4,060.14	73.36	748.28	1,125.11	9,242.36	3,841.40	497.82
2006							
Average	4,007.87	80.06	697.39	1,103.93	8,446.95	1,027.86	278.53
SD	4,090.35	83.82	748.31	1,133.05	13,199.50	1,944.96	344.9
2007							
Average	4,035.13	86.83	681.55	1,110.40	11,200.77	2,239.50	248.26
SD	4,117.38	92.65	725.48	1,138.86	18,123.42	5,538.02	310.73
2008							
Average	4,070.46	87.63	670.76	1,110.07	12,408.95	4,037.09	219.33
SD	4,152.84	90.60	706.51	1,127.17	16,932.05	19,378.28	344.51

Source: Own elaboration from Ofwat data.

period of study, we can conclude that the volume of water supplied by connection started to decline from 2004. The total number of written complaints remained almost constant until 2006 when it began to increase dramatically, doubling in 2008 the values of 2001. An opposite pattern is observable in relation to the number of properties below the reference level since from 2001 to 2008 they decreased significantly (82%). Regarding unplanned interruptions, no trend is observable and the number of these undesirable episodes seems to be random. A further analysis of the evolution of inputs and outputs and how productivity has changed across the time would be very interesting. However, the aim of this study is rather to test if the introduction of the service quality to customers has any effect on water utilities' performance measurement.

Figure 1(a)–(c) show the dispersion of the three service quality variables across water companies which is explained by two factors: different size and different performance of the companies evaluated.

4. Results and discussion

First, the technical efficiency of the 22 English and Welsh water companies was evaluated by solving Equation (3), i.e., without introducing variables representatives of the service quality to customers.

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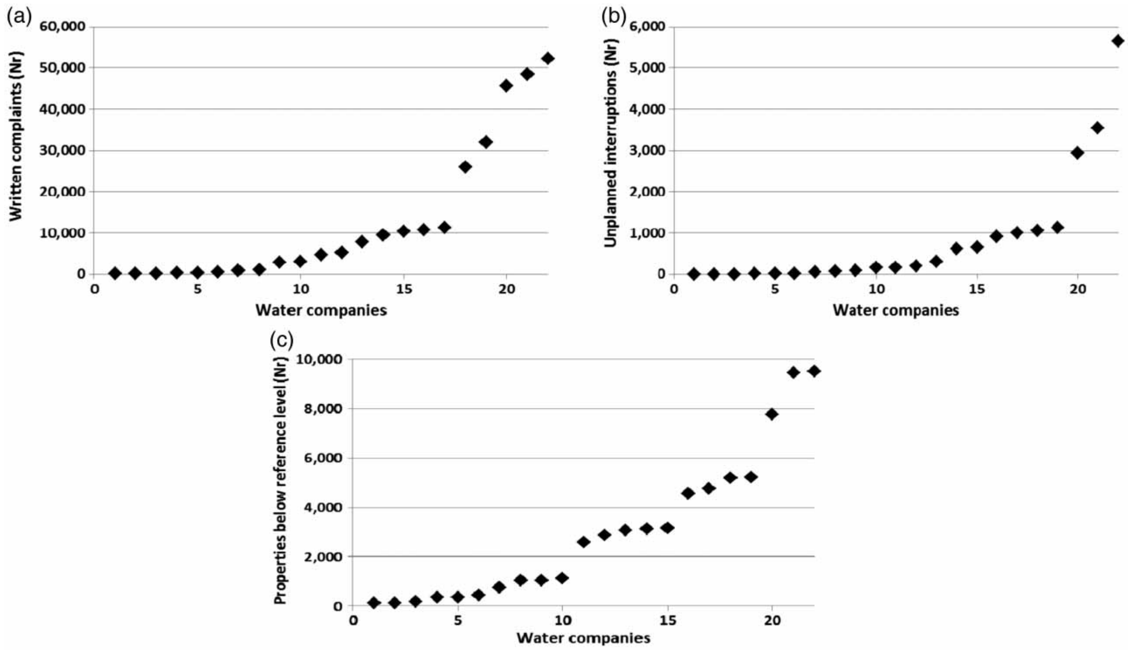

Fig. 1. (a) Number of written complaints for the 22 English and Welsh water companies. (b) Number of unplanned interruptions of the 22 English and Welsh water companies. (c) Number of properties below the reference level of the 22 English and Welsh water companies.

Table 2 displays the relative efficiency scores for the 22 water companies evaluated in the 2001–2008 period.

Before commenting on these results, it should be noted that a production frontier was computed for each year evaluated and subsequently the efficiency of each water company was calculated relative to the frontier in each period. The purpose of estimating the efficiency of a set of years instead of a single year is to detect possible inconsistencies in the data since, as has been reported, DEA does not account for possible noise. In this sense, Table 2 and Table 3 show that the mean efficiency scores for the eight years assessed are very similar (standard deviations are 0.012 and 0.025 for quantity and quality-adjusted approaches, respectively). This indicates that our sample data is consistent. Moreover, because one frontier is calculated for each year there is no sense in comparing the evolution of the efficiency scores across years. As this issue is not the main concern of this study, we leave it for future research.

Coming back to the results of the efficiency assessment without introducing service quality variables, the mean of the individual efficiency scores is 0.922, i.e., the water companies in our sample are producing, on average, 92.2% of their potential outputs. The mean technical efficiency of the English and Welsh companies is pretty high confirming that it is a mature industry. In this context, water companies should focus on achieving other goals such as improving the service quality to customers. Our findings are consistent with previous studies and with our motivation to develop this study.

Focusing on efficiency scores at water company level, Table 2 shows that four of the 22 water companies are efficient, i.e., they may be considered as reference companies. It is observed that the company which is the farthest from the efficient frontier is company C20 whose efficiency score is 0.731. Therefore, this company is the one with the greatest room for improvement from a managerial point of view.

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Table 2. Quantity efficiency scores of the 22 English and Welsh water companies.

Water company	2001	2002	2003	2004	2005	2006	2007	2008	Average	Type
C1	0.812	0.827	0.822	0.890	0.977	0.994	1.000	1.000	**0.915**	WaSC
C2	0.771	0.762	0.748	0.783	0.770	0.847	0.808	0.795	**0.786**	WoC
C3	0.999	0.975	1.000	1.000	1.000	1.000	1.000	1.000	**0.997**	WoC
C4	0.956	0.960	0.977	0.976	1.000	1.000	0.979	0.982	**0.979**	WoC
C5	0.951	0.919	0.829	0.920	0.931	0.977	0.844	0.867	**0.905**	WoC
C6	1.000	1.000	1.000	1.000	1.000	0.984	0.931	0.958	**0.984**	WoC
C7	0.877	0.849	0.833	0.840	0.856	0.908	0.840	0.921	**0.866**	WoC
C8	0.812	0.799	0.798	0.706	0.631	0.836	0.830	0.783	**0.775**	WoC
C9	0.898	0.934	0.846	0.860	0.877	0.915	0.928	0.922	**0.898**	WaSC
C10	0.974	1.000	0.957	0.961	0.915	1.000	1.000	1.000	**0.976**	WaSC
C11	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C12	0.922	0.915	0.909	0.898	0.889	0.880	0.883	0.879	**0.897**	WoC
C13	1.000	0.966	0.933	0.929	0.959	1.000	0.990	0.956	**0.967**	WaSC
C14	0.957	0.955	0.950	0.947	1.000	0.993	0.969	0.985	**0.969**	WoC
C15	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
C16	0.781	0.844	0.831	0.792	0.746	0.676	0.733	0.708	**0.764**	WaSC
C17	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C18	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
C19	0.903	0.928	0.904	0.913	0.921	1.000	0.989	0.962	**0.940**	WoC
C20	0.609	0.655	0.678	0.697	0.687	0.824	0.862	0.832	**0.731**	WaSC
C21	1.000	0.951	0.957	0.995	0.893	0.948	0.929	0.916	**0.949**	WaSC
C22	0.960	1.000	1.000	1.000	1.000	1.000	0.918	1.000	**0.985**	WaSC
Average	**0.917**	**0.920**	**0.908**	**0.914**	**0.911**	**0.945**	**0.929**	**0.930**	**0.922**	

Table 3 shows the technical efficiency scores when the lack of service quality to customers is introduced in the DEA model as undesirable outputs (Equation (9)). The mean for the quality-adjusted scores of efficiency is 0.908, i.e., 90.8% of potential outputs are reached. In this case, eight of the 22 water companies are identified as efficient. Hence, double the number of companies are efficient if the efficiency assessment takes into account not just quantity but also service quality variables. Under this approach, the water company with the lowest efficiency score is not C20 but is company C16. This indicates that company C20 has undertaken efforts at an economic cost to provide a better service to customers. However, the traditional measurement of efficiency based only on quantity variables disserves its efficiency score. The opposite occurs with company C16 whose technical efficiency is considerably higher if service quality is omitted in the efficiency assessment (score of 0.764 versus 0.543). These examples illustrate the importance of introducing service quality to customers as variables in the assessment of the technical efficiency of water companies.

After the privatization of the English and Welsh water industry in 1989, the 10 publicly owned Regional Water Authorities formed the WaSCs, which provide water supply and sewerage services, whereas the 33 Statutory Water Companies formed the WoCs, which only provide water supply services. The last column to the right in Tables 2 and 3 identifies the company type. The mean technical efficiency based on quantity variables for WaSCs is 0.919 and for WoCs is 0.925. When service quality variables are introduced to the assessment, the mean technical efficiency for WaSCs is 0.889 and for WoCs is 0.924. These values indicate that WoCs have higher technical efficiency than WaSCs. The opposite trend is reported by Portela *et al.* (2011) who suggested that WaSCs are more

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Table 3. Quality-adjusted efficiency scores of the 22 English and Welsh water companies.

Water company	2001	2002	2003	2004	2005	2006	2007	2008	Average	Type
C1	0.798	1.000	1.000	0.639	0.706	0.793	1.000	1.000	**0.867**	WaSC
C2	1.000	1.000	1.000	1.000	1.000	0.682	0.627	0.649	**0.870**	WoC
C3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C4	0.755	1.000	0.710	1.000	1.000	1.000	0.749	0.653	**0.858**	WoC
C5	0.679	0.739	0.794	0.656	1.000	0.729	0.755	1.000	**0.794**	WoC
C6	1.000	1.000	1.000	1.000	1.000	0.859	1.000	1.000	**0.982**	WoC
C7	0.639	1.000	1.000	0.722	1.000	0.632	0.744	0.600	**0.792**	WoC
C8	1.000	0.683	1.000	0.648	1.000	1.000	0.620	1.000	**0.869**	WoC
C9	1.000	1.000	1.000	1.000	0.729	1.000	1.000	1.000	**0.966**	WaSC
C10	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
C11	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C12	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.596	**0.949**	WoC
C13	1.000	0.838	1.000	1.000	1.000	1.000	1.000	1.000	**0.980**	WaSC
C14	0.771	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.971**	WoC
C15	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
C16	0.559	0.560	0.542	0.521	0.532	0.521	0.573	0.535	**0.543**	WaSC
C17	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C18	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
C19	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WoC
C20	0.445	0.465	0.554	1.000	1.000	1.000	0.666	0.589	**0.715**	WaSC
C21	1.000	0.637	0.628	1.000	1.000	1.000	0.683	0.600	**0.818**	WaSC
C22	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**	WaSC
Average	**0.893**	**0.906**	**0.919**	**0.918**	**0.953**	**0.919**	**0.883**	**0.874**	**0.908**	

cost efficient than WoCs. Nevertheless, in order to verify whether there are statistical differences in the efficiency scores among WaSCs and WoCs, two non-parametric tests (Mann-Whitney U and Kolmogorov-Smirnov Z) were performed. The p-values verified that the two distributions of the technical efficiencies are not statistically significant either for quantity or quality-adjusted approaches. In order to verify this finding, simple ordinary least squares (OLS) and Tobit regressions of the efficiency scores for 2008 versus the dummy of being a WaSC or WoC were performed. A positive but statistically insignificant coefficient was reported for both cases: 0.0057333 and 0.0029683, respectively. This implies the possibility of the existence of economies of scope among water and sewerage services but this evidence was statistically insignificant. Therefore, no conclusion can be reached about whether the typology of the water companies affects their efficiency scores.

In order to further analyse the impact of introducing service quality variables into the assessment of technical efficiency, Table 4 depicts the average of the quantity and quality-adjusted efficiency scores and the differences between them for each of the 22 water companies evaluated. A negative value indicates that the quantity score of efficiency is higher than the quality-adjusted score. On the other hand, a positive value reflects that the quality-adjusted efficiency score is higher than the one estimated using the quantity approach.

The average difference in efficiency scores between quality-adjusted and quantity approaches is negative (−0.014); thus technical efficiency of English and Welsh water companies is higher if service quality variables are omitted in the assessment procedure. Nevertheless, the quality-adjusted efficiency

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Table 4. Quantity and quality-adjusted efficiency scores of the 22 English and Welsh water companies and their difference.

Water company	Quantity (1)	Quality-adjusted (2)	Difference (2)-(1)
C1	0.915	0.867	−0.048
C2	0.786	0.870	0.084
C3	0.997	1.000	0.003
C4	0.979	0.858	−0.121
C5	0.905	0.794	−0.111
C6	0.984	0.982	−0.002
C7	0.866	0.792	−0.073
C8	0.775	0.869	0.094
C9	0.898	0.966	0.069
C10	0.976	1.000	0.024
C11	1.000	1.000	0.000
C12	0.897	0.949	0.053
C13	0.967	0.980	0.013
C14	0.969	0.971	0.002
C15	1.000	1.000	0.000
C16	0.764	0.543	−0.221
C17	1.000	1.000	0.000
C18	1.000	1.000	0.000
C19	0.940	1.000	0.060
C20	0.731	0.715	−0.016
C21	0.949	0.818	−0.130
C22	0.985	1.000	0.015
Average	**0.922**	**0.908**	**− 0.014**
SD	**0.086**	**0.119**	**0.077**

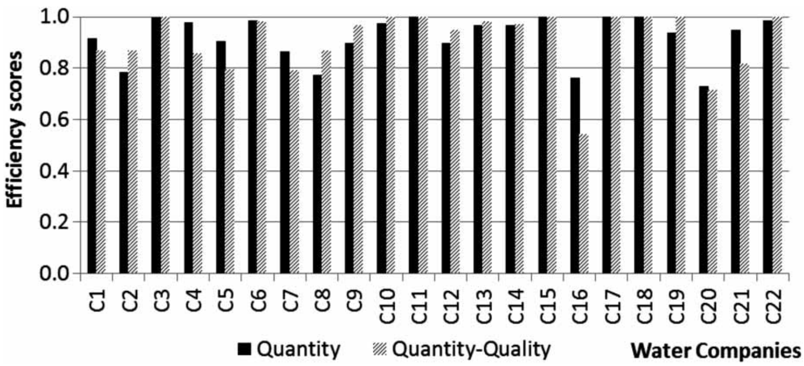

Fig. 2. Quantity and quality-adjusted efficiency scores of the 22 English and Welsh water companies.

scores have a higher SD than quantity efficiency scores. Therefore, a further analysis focusing on individual water companies rather than average values is needed.

As shown in Figure 2, 10 out of the 22 water companies have a positive difference in their efficiency scores, i.e. show higher technical efficiency scores if service quality variables are introduced in the efficiency assessment. This means that following a traditional efficiency evaluation based on quantity

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variables, these 10 companies are clearly penalized. It illustrates that they provide a high service quality to customers, which is ignored in the quantity-based approach. Water companies C2 and C8 should be highlighted, whose efficiency improvement in relation to the quantity-based assessment is around 8.4% and 9.4% respectively. On the other hand, eight out of the 22 water companies exhibit lower efficiency if service quality variables are included in the efficiency assessment with company C16 being the most negatively affected by performing a quality-adjustment assessment. In other words, these eight companies are the ones favoured by ignoring service quality to customers in their efficiency assessment. The four companies that are efficient based on the quantity approach (C11, C15, C17 and C18) are also efficient based on the quality-adjusted approach. However, four additional companies (C3, C10, C19 and C22) are efficient when service quality variables are introduced in the efficiency assessment.

Summarizing, the introduction of the service quality to customers affects performance of the water companies as shown by the difference between quantity-based and quality-adjusted assessment of technical efficiency. To verify from a statistical point of view whether introducing service quality variables affects the performance of water companies, statistical hypothesis tests must be performed. Because efficiency scores do not follow a normal distribution, parametric tests cannot be conducted. As an alternative, two non-parametric tests, namely Mann-Whitney U and Kolmogorov-Smirnov Z, are conducted. The null hypothesis is that efficiency scores for the two approaches followed had no significance difference. The p-value for both tests is <0.001 and therefore, the hypothesis is rejected. In other words, the distribution of quantity-based and quality-adjusted efficiency scores is statistically different.

In order to test the similarity of the ranking of water companies regarding their efficiency scores based on quantity and quality variables, the Spearman's rho and Kendall's Tau correlation coefficients were computed. These are non-parametric measures of statistical dependence between two variables. They measure how well the relationship between two variables (quantity and quality-adjusted efficiency scores in our case study) can be described using a monotonic function. If each of the variables is a perfect monotone function of the other, then the correlation coefficient is $+1$ or -1. In our case study, the Spearman's rho and Kendall's Tau correlation coefficients between quantity and quality-adjusted efficiency scores were 0.8 and 0.6, respectively. This means that the ranking of water companies regarding their efficiency changes when service quality variables are introduced in the assessment.

Our study is of great interest from a policy perspective since it is known that in regulated water sectors benchmarking is a useful tool to compare the relative performance of different companies. It informs the public, policy-makers and regulators about deviations from best practices identifying the poorly performing water companies that need managerial or technical improvements. Evaluating the performance accounting for the service quality dimension of water services acquires special relevancy in countries or regions where the revision of water prices is linked in some way to the relative efficiency of the water companies.

While is not our intention to provide a detailed description of the English and Welsh system for updating water prices, it is an example that clearly illustrates the interest and usefulness, from a policy point of view, of the methodology and empirical application developed in this study. In England and Wales, the regulator (Ofwat) was given the duty to administer a retail prices index (RPI) + K price cap regime. The 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 programmes (Saal *et al*., 2007; De Witte & Marques, 2010). Therefore, although the price cap

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regulation creates an incentive to increase efficiency and innovation it does not take into account service quality to customers. Therefore, water companies that provide better service quality at the expense of higher operational costs are penalized in the water price review. To promote the improvement of service quality to customers in the English and Welsh water sector, the X factor used to set the periodic growth rate of the water price for each company should be estimated taking into account some service quality variables. Furthermore, in light of the fact that water services are paid for by all citizens applying the principle of full cost recovery, identifying water companies that provide a high quality and cost efficient water service also has interest for the whole of society.

Regarding the limitations of our study, it should be noted that three variables have been considered in the efficiency assessment to introduce service quality issues. In this sense, there are two main reasons for which it is impossible to account for all variables representing the quality of the service. Firstly, from a methodological point of view, as reported in Section 3 (sample and data description), the limited number of water companies did not allow us to introduce additional undesirable outputs in the assessment. Second, while Ofwat provides a comprehensive database, it does not contain information for some variables that would be interesting to introduce in the efficiency assessment. Another limitation is that DEA studies do not allow the incorporation of environmental (non-controllable) factors in the performance assessment (Da Cruz & Marques, 2014). As reported by Berg & Marques (2011), only about 35% of non-parametric studies carried out to assess the performance of water companies include the operation environment. Moreover, there might be other reasons that explain differences across companies in terms of technical efficiency and quality of service. Bloom *et al*. (2014) suggested that variations in management practices can be an important factor in understanding the heterogeneity of firm productivity. Product market competition, ownership and governance, human capital (e.g. education level of managers and employees), and information and knowledge of the industry are significantly correlated with high management scores and therefore higher efficiency and productivity. Monitoring (how well do companies monitor what goes on inside their firms and use this for continuous improvement?), targets (do companies set the right targets, track the right outcomes, and take appropriate action if the two are inconsistent?) and incentives (are companies promoting and rewarding employees based on performance, and trying to hire and keep their best employees?) have been defined as areas where good or bad management across firms could be evaluated (Bloom & van Reenen, 2007, 2010). Hence, future research on this issue should focus on integrating other variables as undesirable outputs and on evaluating the influence of environmental variables in efficiency scores. Moreover, to assess the robustness of our findings, other methodological approaches such as order-m and order-alfa could be applied. These are based on a partial frontier method that uses part of the sample to compute efficiency scores and, therefore, is less sensitive to outliers (De Witte & Marques, 2010; Carvalho & Marques, 2011). Finally, quantifying some impacts of management (Bloom & van Reenen, 2007, 2010; Bloom *et al*., 2014) would be a fascinating avenue for further research to better understand variations in efficiency and productivity across water companies.

5. Conclusions

The assessment of the technical efficiency of water companies has proven to be a useful tool both for water utilities and water authorities. The importance of performing benchmarking procedures is specially marked in countries where the water sector has been privatized and regulated. Despite the

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significant development of empirical studies dealing with the objective of measuring the efficiency and productivity of water utilities, very few of them account for service quality.

The objective of this study is to explore the role of service quality to customers in the efficiency assessment of water companies. In doing so, the technical efficiency of the English and Welsh water companies has been computed following two approaches: (i) traditional assessment based on quantity variables and (ii) alternative assessment considering quantity and service quality variables.

From a methodological point of view, this study is pioneering in integrating the lack of service quality to customers as undesirable outputs in a DEA-based framework in the water sector. To the best of our knowledge, only Picazo-Tadeo *et al*. (2008) and Hernández-Sancho *et al*. (2012) follow this approach. However, they focused on managerial efficiency while our study addresses directly the service quality to customers issues by introducing the number of complaints, unplanned interruptions and properties below the reference level as undesirable outputs.

An empirical application is developed to evaluate the quantity and quality-adjusted efficiency of the 22 WaSCs and WoCs providing drinking water services in England and Wales. Our main findings are as follows. First, the quantity-based approach reveals a high level of technical efficiency illustrating that the English and Welsh water industry is mature and one of the challenges it faces is improving the service quality. Second, introducing service quality variables in the evaluation decreases slightly the average scores of technical efficiency. Third, no conclusion can be reached about whether the typology of the water companies (WaSCs or WoCs) affects both their quantity and quality-adjusted efficiency scores. Fourth, 10 out of the 22 water companies exhibit higher quality-adjusted efficiency scores than quantity-based ones. Therefore, the traditional efficiency assessment penalizes their performance. On the other hand, eight out of the 22 water companies are favoured if service quality variables are ignored in the measurement of the efficiency. The four efficient water companies based on the quantity approach are also efficient under the quality-adjusted approach. Finally, the distribution of quantity-based and quality-adjusted efficiency scores is statistically different.

From a policy perspective, both the methodology and the empirical application developed in this study are of great interest for company managers and water regulators. The integration of service quality variables acquires special relevance in countries or regions, such as England and Wales, where the water price revision is carried out based on benchmarking procedures. The measurement of efficiency following a quality-adjusted approach would stimulate water companies to improve service quality to customers which is a desirable objective for society and, moreover, to assist regulators to improve incentives.

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