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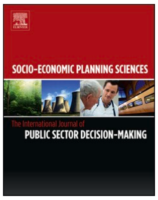

Performance assessment of water companies: A metafrontier approach accounting for quality of service and group heterogeneities

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ABSTRACT

The assessment of water companies' efficiency, productivity and quality of service is part of the process to set water tariffs and therefore, is relevant for regulators and customers. However, the water industry involves several heterogeneous water companies. Following a pioneering approach, this study estimates productivity change and its drivers considering the non-homogeneous nature of the water companies and incorporating quality of service variables as undesirable outputs. In doing so, the metafrontier Malmquist Luenberger productivity index was estimated for a sample of English and Welsh water and sewerage companies (WaSCs) and water only companies (WoCs) over the years 2001–2018. Results reveal that WoCs performed slightly better than WaSCs as WaSCs did not manage to adopt best industry's practice. By contrast, WoCs exhibited notable technical progress. From a policy perspective, we linked the results from productivity change with the regulatory cycle of the English and Welsh water industry. It is found that the 2004, 2009 and 2014 price reviews appeared to have a positive impact on industry's productivity. The methodological approach followed in this study is of great interest for water regulators as it shows how to integrate both quality of service variables and water companies' heterogeneity in productivity change assessment.

1. Introduction

The water industry consists of complex infrastructure and non-infrastructure systems that need to be operated and maintained to ensure exceptional quality of drinking water supplied to customers and of wastewater treated before disposed to the environment [1]. Because of its monopolistic characteristics, the evaluation of efficiency and productivity of the water industry becomes of great importance for water regulators and policy makers. This is evident from the wide research that the water industry has experienced so far in Europe and beyond (for a review on this topic see for instance, Ref. [2,3]. Moreover, the assessment of productivity change can be part of the process for setting water tariffs which is done by the regulator who evaluates and approves water companies' business plans. This is the case of the water industry in England and Wales which was privatized in 1989. As a result of the privatization process, Water and Sewerage Companies (WaSCs) and Water Only Companies (WoCs) were formed to provide both water and sewerage services and water services only, respectively. The Water Services Regulation Authority (Ofwat) was formed to regulate water companies' performance, keep customers' bills affordable and protect the environment.

Most of previous studies evaluating the efficiency of water services in England and Wales have assumed that WaSCs and WoCs operate under the same production frontier. However, this may not be the case as Saal and Parker [4] and Bottasso et al. [5] highlighted. Since the water industry consists of several heterogeneous units (water companies), failure to take into account group heterogeneities in a benchmark analysis may lead to biased measures in efficiency and productivity. This the reason why the metafrontier concept was introduced by Hayami [6] and further developed by Battese et al. [7] and others; to allow the comparison of companies with different technologies. The metafrontier technique denotes an encompassing frontier of all possible efficient frontiers for a heterogeneous group [8,9].

The metafrontier approach has been applied in the water industry to

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compare companies from different countries or different types of companies (e.g. Ref. [10–14]. It was previously used to assess the efficiency of WaSCs and WoCs using parametric (econometric) techniques such as Stochastic Frontier Analysis (SFA) by Molinos-Senante and Maziotis [9]; 2019b) and non-parametric techniques such as Data Envelopment Analysis (DEA) by Molinos-Senante et al. [15]. Moreover, Portela et al. [16] and Molinos-Senante et al. [13,14] studied the productivity change of the water industry using a metafrontier Malmquist productivity index. However, the limitation of the above studies is that they did not include in their analysis any quality of service variables in the form of undesirable outputs that can directly impact the production process. As several previous studies highlighted (e.g. Ref. [3,17–19], improvements in the quality of service and environmental variables require higher costs for the water companies and thus, it is of great interest to assess their direct impact on the production.

To overcome these limitations, the objectives of this study are twofold. The first is to evaluate the productivity change of English and Welsh water companies taking into account group heterogeneities (WaSCs and WoCs) and quality of service. In doing so, we apply, for first time, the metafrontier Malmquist-Luenberger Productivity (MMLP) index developed by Oh [20] in the English and Welsh water industry over the years 2001–2018. This index allows us to estimate productivity change by taking into account the non-homogeneity nature of the water companies (WaSCs and WoCs) and by directly incorporating quality of service variables as undesirable outputs [21,22]. Unlike parametric (econometric) approaches where a functional form for the technology needs to be specified prior to estimation, a parametric approach does not require this strong assumption [23]. Moreover, it does not assume a distribution for the inefficiency as parametric approaches do. Thus, a non-parametric approach is used in this study. The second objective is to quantify the drivers of productivity change by decomposing the MMLP index into efficiency change (EC), best practice gap change (BPC) and technological gap change (TGC). Finally, the estimated productivity results are linked with the English and Welsh water regulatory cycle to draw several interesting policy implications.

This study contributes to the literature on the topic of performance assessment of water companies by: 1) evaluating the productivity change of English and Welsh water companies by considering simultaneously group heterogeneities and quality of service employing a robust and reliable index such as the MMLP index. While the MMLP index has been widely applied in the energy and manufacturing sectors (e.g. Ref. [20,24], it has hardly been researched in the water sector (e.g. Ref. [25]. To the best of our knowledge, there are not any studies evaluating and comparing the productivity of WaSCs and WoSCs in England and Wales using the MMLP index and; 2) decomposing the productivity change of water companies in three drivers namely: EC, BPC and TGC.

The paper unfolds as follows. Section 2 presents the methodology used in this study. Section 3 exhibits the study site and the variables employed to conduct the empirical application whose results are shown and discussed in Section 4. Section 5 links productivity change estimations with the regulatory cycle of the English and Welsh water industry. The final section concludes.

2. Methodology

Before we discuss the computation of the MMLP index and its drivers, we first introduce the concepts of desirable and undesirable outputs and directional distance function. Let's assume that we have Q Decision Making Units (DMUs) $(j=1,..,Q)$ over T time periods $(t=1,..,T)$ that employ a vector of inputs X to generate a vector of desirable outputs Y and a vector of undesirable outputs B. Then we can define the production possibility set (*PPS*) at any time t as follows [26]:

$$PPS_t=\{(X_t,Y_t,B_t)|X_t \ can \ generate(Y_t,B_t)\} \quad where \ \ t=1,..,T \tag{1}$$

The introduction of undesirable outputs in the production process requires the discussion of the following properties [20,27]:

$$If \ (Y,B)\in PPS \ and \ 0\le\phi\le 1 \ \rightarrow \ (\phi Y,\phi B)\in PPS \tag{2a}$$

$$If \ (Y,B)\in PPS \ and \ B=0 \ \rightarrow Y=0 \tag{2b}$$

$$If \ (X,Y,B)\in PPS \ and \ Y^{'}\le Y \ \rightarrow \ (X,Y^{'},B)\in PPS \tag{2c}$$

The first condition (2a) reflects the weak disposability of outputs which suggests that undesirable outputs can't be reduced without reducing desirable outputs [26]. The second condition (2b) refers to the null-jointness assumption which suggests that the undesirable outputs are part of the production process [28]. The third condition (2c) shows the strong disposability of outputs. This means that the desirable outputs can be reduced without the need to reduce the undesirable outputs [24].

Due to the existence of undesirable outputs, we need to define a directional distance function on the production possibility set of Eq. (1) [29]. The directional distance function at any time t is defined as follows:

$$\overrightarrow{D_t}(X_t,Y_t,B_t,g_Y,g_B)=max\{\beta: \ (Y_t+\beta g_Y,B_t-g_B)\in PPS\} \tag{3}$$

where g_Y *and* g_B denote the directional vectors for desirable and undesirable outputs, respectively. These vectors imply that the desirable outputs can increase, and the undesirable outputs can decrease [28]. The value of the directional distance function at time t, $\overrightarrow{D_t}$, captures the distance between the observation (Y_t,B_t) and a point $(Y_t+\beta g_Y,B_t-g_B)$ on the frontier [26]. To simplify notation for the remaining sections, we follow Oh's [20] approach and we replace $\overrightarrow{D_t}(X_t,Y_t,B_t,g_Y,g_B)$ in Eq. (3) with $\overrightarrow{D_t}(X_t,Y_t,B_t)$.

The next step to compute the MMLP index is to define three benchmark technological levels: i) contemporaneous benchmark technology, ii) intertemporal benchmark technology, and iii) global benchmark technology [25]. These technologies are defined based on Tulkens and Vanden Eeckaut [30] and Oh [20] below.

The contemporaneous benchmark technology at any time t of a group K_q where q denotes the number of DMUs (already defined above) can be represented as:

$$PPS^C_{t,K_q}=\{(X_t,Y_t,B_t)|X_t \ can \ generate \ (Y_t,B_t)\} \quad where \ \ t=1,\dots,T \tag{4}$$

The contemporaneous benchmark technology functions as a reference production set which includes data for each group K_q made at a particular time period t [30–32].

The intertemporal benchmark technology at any time t of a group K_q derives a single production possibility set that includes data for the whole time period for the group K_q [30]. The intertemporal benchmark technology is defined as:

$$PPS^I_{t,K_q}=PPS^C_{1,K_q}\cup PPS^C_{2,K_q}\cup\dots\cup PPS^C_{T,K_q} \quad where \ \ t=1,\dots,T \tag{5}$$

It is assumed that DMUs (water companies in our study) in one intertemporal benchmark technology can't have easy access to different intertemporal benchmark technologies [31].

The global benchmark technology at any time of all groups derives a single production possibility set that includes data for the entire period for all groups [30]. Thus, the global benchmark technology is specified as follows:

$$PPS^G_{t,K_q}=PPS^I_{1,K_q}\cup PPS^I_{2,K_q}\cup\dots\cup PPS^I_{T,K_q} \quad where \ \ t=1,\dots,T \tag{6}$$

Based on the above definitions we can proceed with the definition of the MMLP index. According to Oh [20] the MMLP index is defined based on the global benchmark technology and has the following form assuming two time periods, t and $t+1$:

$$MMLP(X_t,Y_t,B_t, \ X_{t+1},Y_{t+1},B_{t+1})=\frac{1+\ \overrightarrow{D^G_t}(X_t,Y_t,B_t)}{1+\overrightarrow{D^G_{t+1}}(X_{t+1},Y_{t+1},B_{t+1})} \tag{7}$$

where $\overrightarrow{D^{G}}(X,Y,B)$ denotes the directional vectors for desirable and undesirable outputs for the global benchmark technology for two time periods t and $t+1$. If MMLP is greater than 1, then it means improvements in productivity, whereas a value lower than 1 suggests productivity losses [33]. If MMLP is equal to 1 then it implies no changes in productivity. Oh [20] suggested that the MMLP index in Eq. (7) can be decomposed as follows:

$$MMLP(X_t,Y_t,B_t,\ X_{t+1},Y_{t+1},B_{t+1}) = \frac{1+\ \overrightarrow{D_t^{G}}(X_t,Y_t,B_t)}{1+\overrightarrow{D_{t+1}^{G}}(X_{t+1},Y_{t+1},B_{t+1})} = \frac{1+\ \overrightarrow{D_t^{C}}(X_t,Y_t,B_t)}{1+\overrightarrow{D_{t+1}^{C}}(X_{t+1},Y_{t+1},B_{t+1})} \times \left\{\frac{1+\ \overrightarrow{D_t^{I}}(X_t,Y_t,B_t)}{1+\ \overrightarrow{D_t^{C}}(X_t,Y_t,B_t)} \times \frac{1+\ \overrightarrow{D_{t+1}^{C}}(X_{t+1},Y_{t+1},B_{t+1})}{1+\overrightarrow{D_{t+1}^{I}}(X_{t+1},Y_{t+1},B_{t+1})}\right\}$$
$$\times\left\{\frac{1+\ \overrightarrow{D_t^{G}}(X_t,Y_t,B_t)}{1+\ \overrightarrow{D_t^{I}}(X_t,Y_t,B_t)} \times \frac{1+\ \overrightarrow{D_{t+1}^{I}}(X_{t+1},Y_{t+1},B_{t+1})}{1+\overrightarrow{D_{t+1}^{G}}(X_{t+1},Y_{t+1},B_{t+1})}\right\} = \frac{TE_{t+1}}{TE_t}\times\frac{BPR_{t+1}}{BPR_t}\times\frac{TGR_{t+1}}{TGR_t} = EC\times BPC\times TGC \tag{8}$$

The first term, *EC,* in Eq. (8) is defined as efficiency change and it measures how technical efficiency changed within a group between time period t and $t+1$ [33]. This term captures therefore the “catch-up” effect from an economic perspective and shows how a DMU (or a water company) moved closer to the contemporaneous benchmark technology [28]. If EC is greater than 1, then the DMU achieved gains in efficiency whereas a value lower than 1 suggests efficiency losses. The second term, *BPC,* is defined as best practice gap change and from an economic point of view is considered as “technical change” or “innovation effect” within a group [24]. If BPC is greater than 1 (less than 1) then it means that the contemporaneous technology shifted closer (far away) to the intertemporal technology [31]. Thus, the contemporaneous frontier shifts in the direction of generating more (less) desirable outputs and less (more) undesirable outputs [24,27]. In other words, if BPC takes a value greater than 1, then technical progress exists. A value less than 1 implies technical regress. The third term, *TGC,* is defined as technological gap change between time period t and $t+1$. From an economic perspective, it is regarded as the “technology catching-up impact” [24]. If TGC is greater than 1 then it suggests that the gap in technology between the intertemporal technology for a particular group and the global technology has reduced [28]. Thus, TGC measures the technical leadership impact by a particular group [33].

The last step in the discussion of the MMLP index and its drivers refers to the calculation of the directional distance functions. Following the approach of Oh [20], Chung and Hesmati [24], Sala-Garrido et al. [25], we employed DEA techniques [34] to calculate the following models between two time periods, $r=t,\ \ t+1$:

$$\overrightarrow{D^{df}}\left(X_{h^{`},r},Y_{h^{`},r},B_{h^{i},r}\right)=max\beta \tag{9}$$

subject to

$$\sum_{con}\lambda_{h,r}h,Y^{l}_{h,r}\geq(1+\beta)Y^{l}_{h^{`},r}\quad l=1,2,\ldots,L$$

$$\sum_{con}\lambda_{h,r}h,B^{n}_{h,r}=(1-\beta)B^{n}_{h^{`},r}\quad n=1,2,\ldots,N$$

$$\sum_{con}\lambda_{h,r}h,X^{n}_{h,r}\leq X^{m}_{h^{`},r}\quad m=1,2,\ldots,M$$

$$\lambda_h\geq0$$

where *df* denotes the various types of directional distance functions, contemporaneous, intertemporal and global [25]. The variable $\lambda_{h,r}$ is defined at the intensity variable which shows at what intensity an observation may be used to build the production possibility set [20] and *con* under $\sum$ shows the conditions for building the PPS. Thus, if $df\equiv r$ and $con\equiv\{h\in PPS_{K_q}\}$ then the contemporaneous directional distance function is defined. If $df\equiv I$ and $con\equiv\{h\in K,\ r\in\tau\},\ \tau=1,..,T$ then the intertemporal directional distance function is specified. If $df\equiv G$ and $con\equiv\{h\in K,\ r\in\tau\},\ \tau\ =\ 1,..,T\ and\ K\ =\ K_1\cup K_2\ldots\cup K_q$, then the global directional distance function is defined [20,25].

3. Sample data and description

The sample employed in this study consists of 10 WaSCs and 7 WoCs that supply water services to customers in England and Wales over the period 2001–2018. We selected this period as the evaluation of productivity of the English and Welsh water companies prior to 2001 was widely studied in the past (e.g., Ref. [4,35,36]. As several mergers and acquisitions occurred among WaSCs and WoCs during the period of study, we followed the approach of Molinos-Senante et al. [13,14] and we grouped together the data from those water companies that follow the same pattern as mergers and acquisitions. The data comes from Ofwat’s website and water companies’ annual performance reports.

We selected the inputs, desirable outputs and undesirable outputs based on the existing literature in the English and Welsh water industry and elsewhere. Additionally, based on the number of water companies, inputs and outputs (desirable and undesirable), we needed to fulfil the “Cooper’s rule”. This states that the number of DMUs used in a DEA analysis should be three times greater than the total number of inputs and outputs [23]. Assuming that the number of water companies is q, the total number of outputs is l and the total number of inputs is n, then it must be that $q\geq max\{l\times n,\ 3(l+n)\}$. In our study the “Cooper’s rule” is satisfied as we have 1 input and 4 outputs, whereas the total number of water companies used is 17.

Following past practice (e.g. Ref. [10,16,37], the following variables were selected for our study. Input was proxied by the annual total expenditure, which was the sum of operating and capital expenditure for water services, measured in millions of pounds. The first desirable output was the volumes of water distributed measured in megalitres per year to capture the amount of water that is abstracted and placed in the network [16]. The second desirable output was the number of water connected properties measured in thousands per year as a proxy for urbanization and size [13,14].

Our study used two undesirable outputs to represent the quality of service to customers. Several studies in the past (e.g. Ref. [25,38] demonstrated the importance of including quality of service variables in an efficiency analysis as they affect companies’ costs. For instance, Berg and Lin [39], Kumar and Managi [40], Mbuvi et al. [41] and Maziotis et al. [42] studied water supply interruptions, water leakage, amount of treated water as proxies for water service continuity and quality in developing countries. Other studies in developed countries studied water leakage, drinking water and wastewater treatment quality as proxies for quality of service (e.g., Refs. [11,36,43,44]. Following therefore past evidence we chose as undesirable outputs the volumes of water leakage measured in megalitres per year and the annual number of bursts per kilometer of main. The selection of these undesirable outputs was also done for other reasons. First, it reflects the management

Table 1
Descriptive statistics.

	Variables	Units	Mean	St.Dev.	Minimum	Maximum
Input	Total expenditure	£m	237.61	200.26	15.13	901.39
Desirable outputs	Water connected properties	000s	1448.53	1098.62	115.20	3826.42
	Volumes of water delivered	Ml/year	316179.71	254704.28	22356.25	1049121.97
Undesirable outputs	Water leakage	Ml/year	70348.14	70816.09	3109.80	345304.2
	Bursts per km of main	nr	219.10	115.25	57.00	979.00

Note: Total expenditure is in 2018 prices.

abilities of the water companies to deal with network incidents that may affect the service to customers. Moreover, it reflects the quality of the network and the significant amount of capital investments carried out by water companies over the years to maintain and improve their assets and thus, the service to customers. Furthermore, improvements in water leakage and repairs in mains due to bursts are part of Ofwat's price review process and incentive schemes to improve quality of service to customers [45]. Water companies receive financial awards if they outperform or are penalized if they underperform in quality of service. Descriptive statistics of the variables used in our study are reported in Table 1.

4. Results and discussion

The average results from the estimation of the MMLP index and its drivers are reported in Fig. 1. It is shown that on average productivity slightly increased by 0.6% during the years 2001–2018. This means that assuming that the inputs of the average company remained the same during the years 2001–2018, its water delivered and connected properties could have increased at an annual rate of 0.6% whereas simultaneously reducing water leakage and bursts in mains at an annual rate of 0.6%. A previous study by Molinos-Senante et al. [13,14] reported small losses in the productivity of English and Welsh water companies over the years 2001–2014. However, the authors did not include any quality of service variables in estimating changes in productivity using the metafrontier concept. Our findings are consistent with previous studies by Molinos-Senante and Maziotis [9] who reported positive gains in productivity for the water companies in England and Wales over the years 1991–2016.

The trend in MMLP index showed high volatility during the period of study (see Fig. 1). In particular, an average water company experienced losses in its productivity during the years 2001–07. The years after the 1999 price review average productivity slightly declined at an average rate of 0.64% but this was interrupted during the years 2003–04 where productivity increased by 1.1%. The deterioration in productivity continued in the following years and especially after the implementation of the 2004 price review. It is noted that during the years 2005–06 productivity declined by 4.6% on average which is the lowest level of reduction over the entire period. In the subsequent years (2008–10) productivity substantially progressed at an average rate of 3.2% per year. The period covered from the implementation of the 2009 price review (2011–15) showed a more positive performance for the industry. Although during the years 2010–11 and 2011–12 productivity declined by 1.66% and 3.30%, respectively, then it substantially increased. During the years 2013–14 productivity showed the highest level of increase over the entire period, which reached the level of 11.24%. The last three years of our sample refer to the period covered by the 2014 price review. It is shown that in the last time period (2017–18) average productivity increased by 5.6% whereas during the years 2015–17 it declined by an average rate of 2.25% per year.

In order to better understand what drove the change in productivity in the English and Welsh water industry we need to look at the components of MMLP index, namely: EC, BPC and TGC. The average results indicate that all components positively contributed to changes in productivity. BPC (average value 1.005) contributed more than EC (average value 1.003) and TGC (average value 1.002) to improvements in productivity. This suggests that technology advancements may lead to higher gains in productivity. However, the small but positive values of the three drivers suggest that less efficient water companies need to improve their management practices, and the water industry needs to show more leadership in adopting and inventing new technologies.

Delving into the components of MMLP index, it is shown that average EC during the period of study was 1.003 which suggests that gains in efficiency were small and at the level of 0.3% per year. As EC measures the change in technical efficiency of a water company within its group, its small and positive value suggests that on average less efficient water

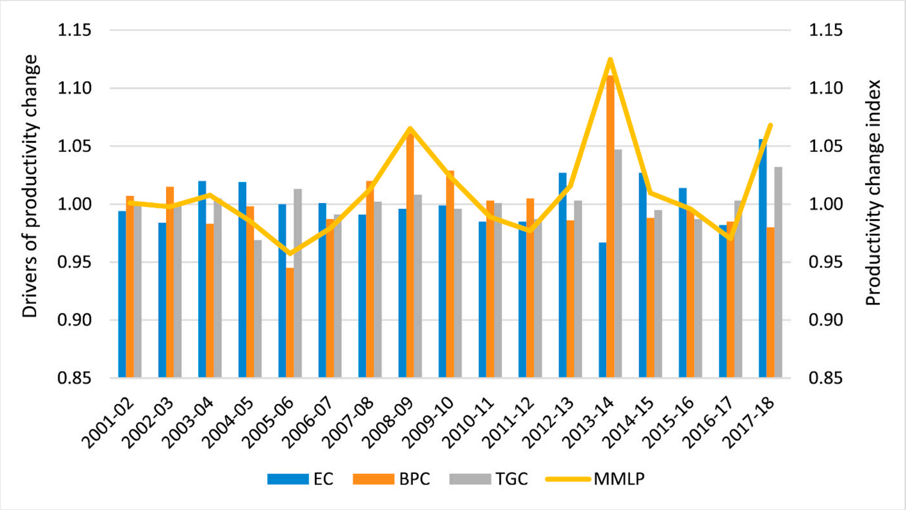

Fig. 1. Average estimates of metafrontier Malmquist Luenberger productivity (MMLP) index and its drivers: efficiency change (EC); best practice gap change (BPC) and technological gap change (TGC).

companies slightly moved closer to the most efficient companies. In other words, the catch-up factor was low during the years 2001–18. EC showed positive results during the years 2003–07. However, water companies experienced losses in their efficiency in the following years. It is noted that during the years 2007–12 the English and Welsh water industry showed a decline in the catching-up effect of 0.9% per year on average. From 2012 onwards EC became more volatile. However, with the exception of two time periods (2013–14 and 2016–17), EC showed positive performance which means that the catch-up effect progressed on average. Overall, the small gains in efficiency over time suggest that on average less efficient water companies need to better manage their day-to day operations and assets so that they can improve their efficiency and quality of service to their customers. This can be done by learning from the most efficient water companies within their group.

The BPC results suggest that on average there was a small increase in technology of 0.6% per year. As BPC is considered as innovation effect or technical change within a group, the result suggests that the water industry experienced small technical progress over the period of study. Its small and positive value implies that the English and Welsh water industry needs further investments in technology. An example of this could be technologies that can better monitor and predict leakages and bursts in their water network. Although the industry showed technical progress during the first two time periods of our sample, this substantially declined the following years. It is noted that during the years 2005–06 technical change declined by 5.49% per year. Technical change had a positive performance during the period 2007–14 and reached its highest value in 2013/14, an increase at the rate of 11.1% per year. However, in the subsequent years technical regress occurred. Overall, the findings indicate that although the water industry is good at catching "innovation efficiency" [24], it still needs to adopt best advances in technology. This finding will help water companies to deliver more water to more connected properties at the same cost and to improve quality of service to customers by reducing water leakages and repairing pipes.

Another component of technical change is the technical gap change (TGC) which shows the technical leadership of the industry. The results show that on average TGC had a small but positive value over time, 1.002. This means that although the English and Welsh water industry did not lack technical leadership over time, its effect on productivity change was low. TGC showed high volatility over time. It remained constant during the first three time periods of our sample and then substantially decreased during the period 2004–05. During the years covered by the 2004 price review (2006–2010) it showed small but positive results. TGC continued to fluctuate in the next periods and reached its peak value in 2013–14 where it showed an increase of 4.7% per year on average. During the last three periods of our sample and with the exception of the period 2015–16, TGC was positive. Overall, the results suggest that the industry needs to show more leadership in inventing new technologies.

Table 2 shows the results of MMLP index and its drivers over time by water company type, i.e., WaSCs and WoCs. The results indicate that on average WoCs performed better than WaSCs (see Fig. 2). It is found that productivity experienced high volatility over the years suggesting that heterogeneities between WaSCs and WoCs may exist. In particular, it is shown that the average MMLP index for WaSC and WoC over the entire period was 0.995 and 1.023, respectively. This means that there was an average annual decrease of 0.5% in WaSC's productivity over the sample period, whereas there was an average annual increase of 2.3% in WoC's productivity over the same period Molinos-Senante et al. [13,14] also found that WoCs were slightly more productive than WaSCs. This finding was further corroborated by Molinos-Senante and Maziotis [9]. WaSC's average productivity showed substantial losses till the years 2006–07 with the exception being the year 2004–05. The subsequent years continued to fluctuate reaching its highest values during the periods 2008–09 and 2013–14, an annual increase of 5.2% and 2.7%, respectively. In the last two periods of our sample average WaSC's productivity deteriorated. Moreover, WoC's average productivity showed considerable gains till the years 2003–04 but these gains were lost in the subsequent years and till 2006–07. Like WaSC's productivity, WoC's productivity fluctuated the following periods. High productivity gains were reported during the periods 2008–09, 2013–14 and 2017–18.

Looking at the components of WaSC's MMLP index, it is concluded that the main factors contributing positively to productivity change were EC and TGC whereas BPC had an adverse impact on productivity. The annual increases in EC and technical leadership over time were at the level of 0.4% and 0.2% per year on average. However, average WaSC experienced a technical regress of 0.6% per year on average which led to an overall deterioration in productivity. Our results are consistent with Molinos-Senante et al. [13,14] where the authors found that EC was the main factor positively influencing WaSC's performance. Our findings imply that on average less efficient WaSCs achieved small efficiency gains by moving closer to the most efficient ones. The average TGC is 0.2% per year which means that the gap between the global and the group technology frontiers has declined [20]. The high volatility in the values of TGC during the years 2001–2018 implies that heterogeneities between WaSCs and WoCs may exist. However, WaSCs were not good in catching "innovation efficiency" within their group. Considerable gains in efficiency occurred during the years 2003–04 and from 2008–09

Table 2
Average estimates of MMLP and its drivers by water company type.

Period	WaSCs				WoCs			
	EC	BPC	TGC	MMLP	EC	BPC	TGC	MMLP
2001–02	1.026	0.962	1.004	0.984	0.947	1.072	0.993	1.005
2002–03	0.971	1.020	1.003	0.986	1.002	1.008	0.995	1.007
2003–04	0.990	1.003	0.998	0.991	1.062	0.954	1.014	1.039
2004–05	1.035	0.999	0.982	1.010	0.996	0.997	0.951	0.946
2005–06	0.996	0.934	1.037	0.957	1.006	0.961	0.978	0.949
2006–07	0.996	0.980	1.000	0.977	1.007	0.996	0.979	0.984
2007–08	0.986	1.016	1.003	1.004	0.999	1.026	1.001	1.025
2008–09	1.008	1.056	0.989	1.052	0.980	1.068	1.034	1.077
2009–10	1.012	1.001	1.001	1.013	0.981	1.069	0.989	1.033
2010–11	1.013	0.966	1.009	0.987	0.945	1.056	0.991	0.979
2011–12	0.956	1.034	0.984	0.958	1.028	0.962	0.992	0.980
2012–13	1.004	1.007	1.013	1.024	1.061	0.957	0.989	1.006
2013–14	0.966	1.053	1.017	1.027	0.967	1.193	1.090	1.235
2014–15	1.046	0.956	0.988	0.982	0.999	1.034	1.004	1.029
2015–16	1.011	1.011	0.993	1.013	1.018	0.972	0.978	0.961
2016–17	1.002	0.953	1.012	0.966	0.952	1.031	0.989	0.960
2017–18	1.045	0.950	1.002	0.978	1.072	1.023	1.076	1.174
Average	1.004	0.994	1.002	0.995	1.001	1.022	1.003	1.023

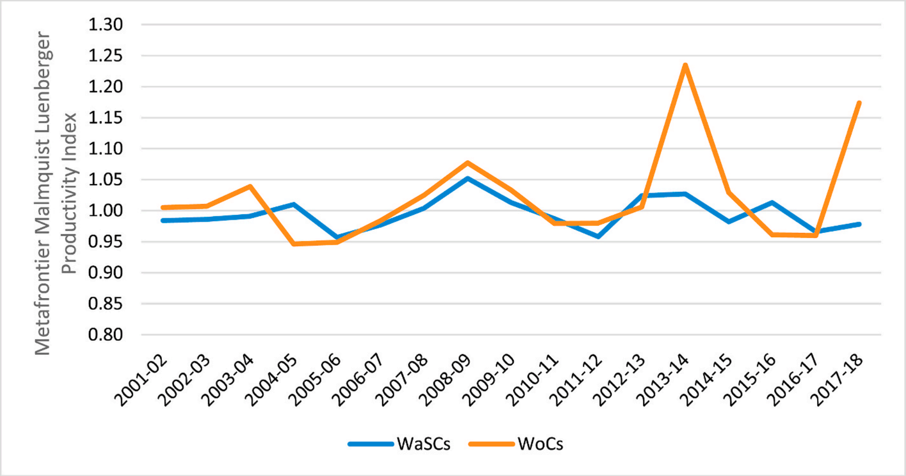

Fig. 2. Average Metafrontier Malmquist Luenberger Productivity Index for water and sewerage companies (WaSCs) and water only companies (WoCs).

onwards with the exception of the periods 2011–12 and 2013–14. Substantial gains in efficiency were evident during the period 2012–2018. High levels of innovation or technical progress were shown during the years 2008–09 and 2011–14. In the last two periods of our sample average WaSC experienced considerable technical regress which was at an annual rate of almost 5%. Technology was mainly led by WaSCs during the periods 2005–08, 2009–11, 2012–14 and 2016–17.

The comparison of the three drivers of MMLP index for WoCs suggests that the main factor influencing the change in their productivity was technical change which increased at annual rate of 2.2% on average. Gains in EC were positive but negligible, at a rate of 0.1% per year on average. This result suggests that WoCs performed well in terms of “innovation efficiency” within their group but they still need to improve their daily management practices. This can be done by learning from the most efficient WoCs. Average WoC’s TGC is at the level of 0.3% per year but it shows high volatility over the period of study. This implies that there are some heterogeneities between WaCs and WoCs. It also appears that WoCs led technology, however, both groups of water companies need to show more technical leadership in inventing new technologies as its effect on productivity is low. Considerable gains in efficiency were mainly evident during the years 2003–04, 2011–13 and 2017–18. Technological advancements within the group were more frequent and mainly occurred from 2008–09 onwards. Technology was led by WoCs mainly during the periods 2003–04, 2007–09, 2013–15 and 2017–18.

5. Productivity change and regulatory cycle

Table 3 links the results from productivity change with the regulatory cycle, which is divided into several sub-periods to reflect the duration of the price review in the English and Welsh water industry. The first sub-period refers to the period covered from the 1999 price review. This was the first price review were the water companies were obliged to reduce the prices charged to customers [35]. As part of the process, Ofwat introduced several incentive schemes to encourage water companies to reduce their costs so that they can regain economic profitability. These included, for instance, a cost reduction target of 2.4% for the industry which was higher than the one determined in the 1994 price review [13,14]. Another example included the introduction of a rolling outperformance incentive where the water companies could maintain cost savings for five years no matter when these savings occurred. Regarding customer service, Ofwat introduced the Overall Performance Assessment (OPA) where the water companies needed to report data on several quality of service variables such as water leakage, properties at risk of low water pressure, flooded incidents on sewers, water quality [46]. Water companies who outperformed were financially rewarded and those who underperformed were penalized. As a result, there were small efficiency gains for both WaSCs and WoCs at the level of 0.5% and 0.2% per year on average. This means that less efficient water companies improved their efficiency toward the most efficient company. However, both WaSCs and WoCs were not productive mainly due to the lack of leadership in inventing new technologies. Ofwat [47] found that water companies may have needed to invest more resources on reducing water leakage and deal with incidents such as bursts in mains that cause interruptions in the supply of water to customers. On average the water companies continued to keep services to customers and customers were satisfied with the level of service they received [48].

Table 3
Average productivity change and its drives per regulatory cycle.

	2002–05	2006–10	2011–15	2016–18
Sample data				
EC	1.004	0.998	0.998	1.017
BPC	1.001	1.008	1.019	0.987
TGC	0.993	1.002	1.007	1.007
MMLP	0.995	1.006	1.016	1.005
WaSCs				
EC	1.005	1.000	0.997	1.019
BPC	0.996	0.997	1.003	0.971
TGC	0.997	1.006	1.002	1.002
MMLP	0.993	1.001	0.995	0.986
WoCs				
EC	1.002	0.994	1.000	1.014
BPC	1.008	1.024	1.040	1.009
TGC	0.988	0.996	1.013	1.014
MMLP	0.999	1.014	1.046	1.031

The second sub-period (2006–10) covers the period after the implementation of the 2004 price review and shows that water industry’s productivity slightly improved at an annual rate of 0.6%. Ofwat kept the incentive schemes of the previous price review and it further introduced other incentives where the water companies could share any operating and capital expenditure outperformance with customers. The results indicate that both WaSCs and WoCs improved their productivity. For WaSCs this was mainly attributed to their ability of globally leading technology advancements whereas for WoCs this was attributed to their ability to capture in innovation efficiency. Although water companies needed to deal with climate events such as floods in 2008–09 and cold winter conditions in 2009–10, they were able to manage their assets efficiently [49]. On average the water companies met their leakage targets, however, the industry leakage level remained high, almost at the level of 24% [49].

In the next sub-period Ofwat replaced OPA with another scheme called Service Incentive Scheme (SIM) where the water companies received awards (or penalties) if the customers are satisfied (or dissatisfied) with the way the companies dealt with an incident such as leakage, low pressure, or billing enquiries [50]. During the years 2011–15, water industry's productivity further improved at a rate 1.6% per year which was attributed to technical change which progressed at an annual rate of 1.9%. The results indicate that WoCs were more productive than WaSCs mainly due to investing in new technology advancements that helped them to reduce costs and improve quality of service to customers. WoC's productivity improved at an annual rate of 4.6% per year. In contrast, average WaSC's productivity slightly deteriorated by 0.5% per year. Any gains in investing in new technologies and adopting best industries' practices were offset by losses in efficiency leading therefore to a decline in productivity.

The 2014 price review led to a slight increase in water industry's productivity, at a rate of 0.6% per year, which was mainly attributed to gains in efficiency. As part of the price review, Ofwat introduced another financial incentive scheme, called Outcome Delivery Incentives (ODIs), which included a set of indicators to assess the performance of water companies with respect to quality of service and environmental standards. Both WaSCs and WoCs achieved considerable gains in efficiency whereas WoCs seemed to be the innovator group regarding technology enhancing therefore, their productivity. In contrast, WaSCs did not manage to adopt the best industry's practices and thus, their productivity declined. Improving quality of service to customers, such as reduction in water leakage, remains the top priority in Ofwat's policy agenda [45].

Despite the contribution of this study to the current strand of literatures, it is not exempt of limitations. First, the quality of service focused on two variables namely water leakage and bursts per km of main. However, alternative quality of service variables could be integrated in the productivity change assessment. In this context, previous studies [3,13,14,36]; Marques and Simoes, 2020) evidenced the importance of considering compliance with drinking water quality standards, pressure standards and energy efficiency. Second, the number of water companies evaluated is 17 which provide drinking water services to all English and Welsh citizens. Nevertheless, according to the methodology employed, this reduced number of water companies limits the number of variables considered to estimate the MMLP index. Given the relevance of the water-energy nexus and the need of reducing greenhouse gas (GHG) emissions associated with the provision of drinking water services [51,52], future research could focus on comparing the productivity change of WaSCs and WoCs (or another groups of water companies, i.e., public vs. private) by integrating the emission of GHG as undesirable outputs. This assessment will provide information not just about the technical efficiency of water companies but also about its environmental performance.

6. Conclusions

Water companies operate under natural monopolies so the establishment of a regulator to assess their performance, protect customers and environment is of great importance. The evaluation of the water companies' efficiency, productivity and quality of service to customers is part of the process to set tariffs. Nevertheless, the water industry consists of several heterogeneous water companies that may have different technological characteristics. In this paper we take into account water company heterogeneities and quality of service in productivity assessment by estimating the MMLP index for several water companies in England and Wales over the period 2001–2018. The MMLP index then is decomposed into three drivers namely EC, BPC and TGC.

The results reveal several interesting conclusions. First, it is found that on average water industry's productivity improved at an annual rate of 0.6%. This suggests that if on average inputs remained fixed during the years 2001–2018, then the delivery of more water to more connected properties may need to increase at annual rate of 0.6%, whereas at the same time, water leakage and bursts in mains may need to reduce by 0.6% per year. Second, all components had a positive impact on productivity. It seems that adopting best industry's practice (BPC) may lead to higher gains in productivity. Moreover, the productivity results showed that on average WoCs performed slightly better than WaSCs. It also revealed some heterogeneities between the two groups as shown by the instability in the values of the productivity index and its drivers over time. Although on average less efficient WaSCs moved closer to the most efficient companies and WaSC's group showed some leadership in investing new technologies, WaSCs did not manage to adopt best industry's practice. Thus, average productivity deteriorated. In contrast, average WoC's productivity improved due to technical progress, i.e., its ability to capture "innovation efficiency". It appears that WoCs led technology, however, they still need to improve their daily operations as efficiency gains within their group were negligible. When linking the productivity results with the regulatory cycle, it is concluded that the 2004, 2009 and 2014 price reviews seemed to have a positive impact on industry's productivity.

Several policy implications can be drawn from the methodology and results of our study. First, the EC of both WaSCs and WoCs was variable across years and water companies. Thus, to improve the efficiency of the water companies, the English and Welsh water regulator should develop and promote a policy of continuous improvement where water companies need to better manage their day-to day operations and assets. In doing so, the water regulator could develop a best available techniques reference document to share positive experiences and practices among water companies. Second, the water regulator should introduce additional policies and/or incentives to improve the quality of service. Thus, water companies need to invest in technologies to better monitor and predict leakages and bursts in their water network. The reduction of water losses not only implies a better performance of the water company but also important environmental benefits which are relevant in a water scarcity context. Hence, the water regulator should partially modify its process to set water tariffs to reward those water companies that make investments in improvements to their supply network benefiting society.

CRediT authorship contribution statement

Manuel Mocholi-Arce: Data curation, Methodology, Software. **Ramon Sala-Garrido:** Data curation, Methodology, Software. **Maria Molinos-Senante:** Conceptualization, Project administration, Writing - original draft. **Alexandros Maziotis:** Conceptualization, Formal analysis, Writing - original draft.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.seps.2020.100948.

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