Output Quality and Sources of Profit Change in the English and Welsh Water and Sewerage Companies

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Abstract

This paper investigates the determinants of profit change over the period 1991-2008 for the Water and Sewerage Companies (WaSCs) in the English and Welsh water and sewerage industry. We firstly apply an input oriented profit decomposition approach following the approach of De Witte & Saal (2010). Then, we make allowances for differences in the quality of output, by decomposing the output effect into high quality and low quality output effect. We decompose profit changes into various factors such as quantity and price effect, technical change, efficiency change, resource mix, product mix and scale effect, without and after controlling for quality. In both cases, the positive impact on profit changes came from substantial improvements in technical change, the cost efficient allocation of resources by substituting labour with capital and small improvements in efficiency gains. The input price and scale effect had a significant negative impact on profit changes. This technique is of great interest for regulators to evaluate the effectiveness of regulation and companies to identify the determinants of profit change and improve future performance, even if sample sizes are limited.

Key words: Profit Decomposition, Productivity, Index Numbers, DEA, Regulation, Water and Sewerage Industry

1.Introduction[1]

A firm's financial performance is commonly measured by its profits. Changes in profits over time can be attributed to changes in both productivity and prices. Comparing changes in productivity and prices allows determination of whether profit change is primarily explained by improvements in productivity or is simply attributable to an increase in output prices which is greater than the change in input prices. However, there are other determinants that might affect profit changes over time such as technical change and efficiency change effect, scale effect, resource and product mix effect. This technique originally developed by Grifell-Tatje & Lovell (1999) can be applied in a regulatory framework to assess the impact of price cap regulation on the financial performance of the regulated companies. This methodology would enable both regulators and regulated companies to better identify the sources of profit variation and aid them in evaluating both the effectiveness of a regulatory price cap scheme and the performance of the regulated companies. Also, profit decomposition enables the regulator to identify those sources of profits that can eventually be passed along to consumers in lower output prices, such as those attributable to productivity gains. Moreover, this methodology can also be used by the regulated companies to identify the determinants of their profit changes and improve future performance, thereby leading to future profit gains.

There were several studies in the past that decomposed profit changes into three sources: a productivity change effect, an activity effect and a price change effect. Grifell-Tatje & Lovell (1999) provided a three-stage output oriented long-run profit decomposition to indentify the sources of profit change within the Spanish banking sector. The authors used Laspeyers and Paasche indicators to decompose economic profits into a quantity and price effect and linear programming methods to measure technical change, efficiency change, resource mix, product mix and scale effect. Also, De Witte & Saal (2010) employed Laspeyers and Paasche indicators and Free Disposal Hull (FDH) techniques to implement an input oriented instead three-stage profit decomposition for the Dutch regulated water industry. Moreover, Lim and Lovell (2006b) provided an output oriented short-run profit decomposition by taking into account the impact of quasi-fixed inputs and applied their decomposition to US

[1] The authors would like to express their gratitude for the support of the Economic and Social Research Council as well as the Office of Water Services (Ofwat), and note that the usual disclaimer applies.

Railroads for the period 1996-2003. In another study, Grifell-Tatje and Lovell (2008) provided another type of profit decomposition to measure productivity and price changes in US post offices. The authors decomposed profits into a quantity, margin and productivity effect by using Bennet indicators and then the productivity effect was further decomposed into a cost efficiency, technical change and scale effect. Finally, Sahoo & Tone (2009) employed both radial and non-radial DEA methods and both Laspeyers & Paasche and Bennet indicators, as weights, to value the contributions of various profit determinants on the Indian commercial banking sector.

The purpose of this paper is the evaluation of various profit drivers such as price changes, productivity changes and activity levels on the financial performance of the Water and Sewerage Companies (WaSCs) over time in the case when the number of observations is limited. Therefore, we firstly, follow the approach of De Witte & Saal (2010) and decompose profits into a quantity and price effect using Bennet indicators to weigh the changes in quantities and prices and then we employ DEA techniques to take into account the impact of efficiency change, technical change and scale effect on profit changes. Moreover, with the exception of De Witte and Saal (2010) which controls for the impact of drinking water density on input requirement through a conditional DEA approach, the studies discussed above do not generally consider exogenous factors in the profit decomposition analysis. Given this gap in the literature, and since the UK water and sewerage industry is characterized by high capital investment programs to improve drinking water quality and environmental standards, we include exogenous characteristics like output quality in a profit decomposition analysis. By making allowances for differences in the quality of output, the output effect is decomposed into high quality and low quality output effect. Finally, we provide a comparison of results from the profit decompositions without and after controlling for quality on Water and Sewerage Companies (WaSCs) in England and Wales over the period 1991-2008.

This paper unfolds as follows. Section 2 discusses the concept of distance functions. It includes an analysis of the decomposition of profits into its components and the Data Envelopment Analysis (DEA) technique in order to estimate the components of the profit decomposition without and with adjustments for quality. Section 3 presents the data that are used in our study followed by a discussion of empirical results. The last section concludes.

2. Methodology

2.1. Distance Functions

We define the production technology at each period t as the set that includes all feasible output - inputs correspondences. The inputs are represented by a positive input quantity vector $X = (X_1, X_2, ..., X_N)$ where N denotes the total number of inputs that a company uses in order to produce a vector of non-negative outputs $Y = (Y_1, Y_2, ..., Y_M)$ where M denotes the total number of outputs. Let us assume that we have a positive vector of input prices $W = (W_1, W_2, ..., W_N)$ and a positive vector of output prices $P = (P_1, P_2, ..., P_M)$. The *production technology* or *production possibility* set for period t is then represented as:

$$S^t = \{(X^t, Y^t) : X^t \text{ can produce } Y^t\}, \qquad \text{where } t = 1,2,....,T \tag{1}$$

Let also the input set, $L^t(Y^t)$, represent the set of all input vectors that can produce a given output vector at period t, Y^t:

$$L^t(Y^t) = \{X^t : X^t \text{ can produce } Y^t\} = \{X^t : (X^t, Y^t) \in S^t\} \tag{2}$$

The input set is assumed to be closed and convex and satisfying strong disposability of inputs. Strong disposability of inputs means excess inputs can be disposed at no cost. The lower bound of an input set is the input isoquant given by:

$$I^t(Y^t) = \{X^t : X^t \in L^t(Y^t), \lambda X^t \notin L^t(Y^t), \lambda \prec 1\} \tag{3}$$

Shephard (1970) introduced the input distance function to provide a functional representation of production technology. The input distance function defined as a minimal proportional reduction of the input vector given an output vector at each period t is given by:

$$D_I^t(Y^t, X^t) = \max\{\mu : (X^t / \mu) \in L^t(Y^t)\} \tag{4}$$

For $X^t \in L^t(Y^t), D_I^t(Y^t, X^t) \geq 1$ and for $X^t \in I^t(Y^t), D_I^t(Y^t, X^t) = 1$.

Let us also define the output set, $O^t(X^t)$, which represents the set of all output vectors, Y^t, that can be produced using the input vector, X^t in period t:

$$O^t\left(X^t\right)=\left\{Y^t : X^t \text{ can produce } Y^t\right\}=\left\{Y^t : \left(X^t, Y^t\right)\in S^t\right\}, \quad \text{where } t=1,2,....,T \qquad (5)$$

The output set is assumed to be closed and convex and satisfy strong disposability of outputs and inputs. The outer bound of an output set is its output isoquant:

$$I^t\left(X^t\right)=\left\{Y^t : Y^t \in O^t\left(X^t\right), \lambda Y^t \notin O^t\left(X^t\right), \lambda \succ 1\right\} \qquad (6)$$

Shephard's (1970) output distance function provides another functional representation of production technology. The output distance function defined as a maximal proportional expansion of the output vector given an input vector at each period t is given by:

$$D_o^t\left(Y^t, X^t\right)=\min\left\{\delta : \left(Y^t / \delta\right)\in O^t\left(X^t\right)\right\} \qquad (7)$$

For $Y^t \in O^t\left(Y^t\right), D_O^t\left(Y^t, X^t\right)\leq 1$ and for $Y^t \in I^t\left(X^t\right), D_O^t\left(Y^t, X^t\right)=1$. The distance functions, being radial distance measures, provide the tools with which we will recover the unobserved quantity vectors that we need for the profit decomposition.

2.2. Profit Decomposition Without Controlling for Quality

In this section we follow De Witte and Saal's (2009) approach and provide an input oriented profit decomposition between two time periods t and t+1 using Bennet indicators, average prices and quantities as weights to estimate the contributions of the quantity and price effect to profit change. Let a company's profit in period t, Π^t, be defined as a difference between its total revenues and total costs, $\Pi^t = P^t Y^t - W^t X^t$. Using Bennet indicators, $\overline{P}=1/2\left(P^{t+1}+P^t\right)$, $\overline{W}=1/2\left(W^{t+1}+W^t\right)$, $\overline{X}=1/2\left(X^{t+1}+X^t\right)$, $\overline{Y}=1/2\left(Y^{t+1}+Y^t\right)$ profit change between period t and t+1, $\Pi^{t+1}-\Pi^t$, is decomposed as follows:

$$\begin{aligned}\Pi^{t+1}-\Pi^t &= \overline{P}\left(Y^{t+1}-Y^t\right)-\overline{W}\left(X^{t+1}-X^t\right) \qquad \textit{quantity effect}\\ &+\overline{Y}\left(P^{t+1}-P^t\right)-\overline{X}\left(W^{t+1}-W^t\right) \qquad \textit{price effect}\end{aligned} \qquad (8)$$

The quantity effect captures the contribution to profit changes from a change in output production and input usage, while the price effect shows the contribution to profit

changes from a change in output and input prices. The quantity effect shows that profits may increase due to a rise in output production in excess of the corresponding input rise while the price effect shows that profits may also rise due to an increase in output prices in excess of the rise in input prices. The decomposition of profits into a quantity and price effect involves only observed quantity and price data.

In the second stage the quantity effect can be decomposed into a *productivity* and an *activity* effect as follows:

$$\begin{aligned} &\overline{P}\left(Y^{t+1}-Y^{t}\right)-\overline{W}\left(X^{t+1}-X^{t}\right) && \textit{quantity effect} \\ &=\left[\overline{W}\left(X^{t}-X^{B}\right)-\overline{W}\left(X^{t+1}-X^{C}\right)\right] && \textit{productivity effect} \\ &+\left[\overline{P}\left(Y^{t+1}-Y^{t}\right)-\overline{W}\left(X^{C}-X^{B}\right)\right] && \textit{activity effect} \end{aligned} \tag{9}$$

This decomposition is depicted in Figure 1. $I^{t}\left(Y^{t}\right)$ represents the efficient input boundary, that is the locus of minimum input levels needed to produce a given level of output Y^{t} in period t. The quantity effect as decomposed in (9) makes use of the observed quantities X^{t} to X^{t+1} and of the unobserved quantities $\left(X^{A}, X^{B}, X^{C}\right)$. As can be seen in Figure 1, X^{A} and X^{B} denote the efficient input level that the unit could have used in period t and period t+1 respectively to secure out Y^{t} keeping to the input mix of X^{t}, while X^{C} represents the efficient input level that the unit could have used in period t+1 to secure out Y^{t+1} keeping to the input mix of X^{t+1}.

The productivity effect in (9) compares the distance from X^{B} to X^{t} in period t with the distance from X^{C} to X^{t+1} in period t+1. The difference in these two distances reflects productivity change of the unit as it captures how much closer or further from the 'fixed' efficient boundary of period t+1 the unit has moved over time. When we have $\left(X^{t}-X^{B}\right)>\left(X^{t+1}-X^{C}\right)$ we have a positive contribution to profit change, whereas when we have $\left(X^{t}-X^{B}\right)<\left(X^{t+1}-X^{C}\right)$ we have a negative contribution to profit change.

The activity effect in equation (9) measures the changes in the scale and scope of the activities of a company. When $\left(Y^{t+1}-Y^{t}\right)$ is positive it reflects a rise in output over time while $\left(X^{C}-X^{B}\right)$ when negative reflects a fall in the efficient level of input

needed to secure the output. Thus both the output and the input differences in this case respectively lead to positive contributions to profit change between period t and t+1.

Finally in a third stage decomposition the productivity effect in equation (9) can be further decomposed into an *efficiency change* and t*echnical change* effect while the activity effect can be further decomposed into a *resource mix*, *output mix* and *scale* effect. Figures 1 and 2 depict the decomposition of the productivity and activity effect, which we now elaborate upon.

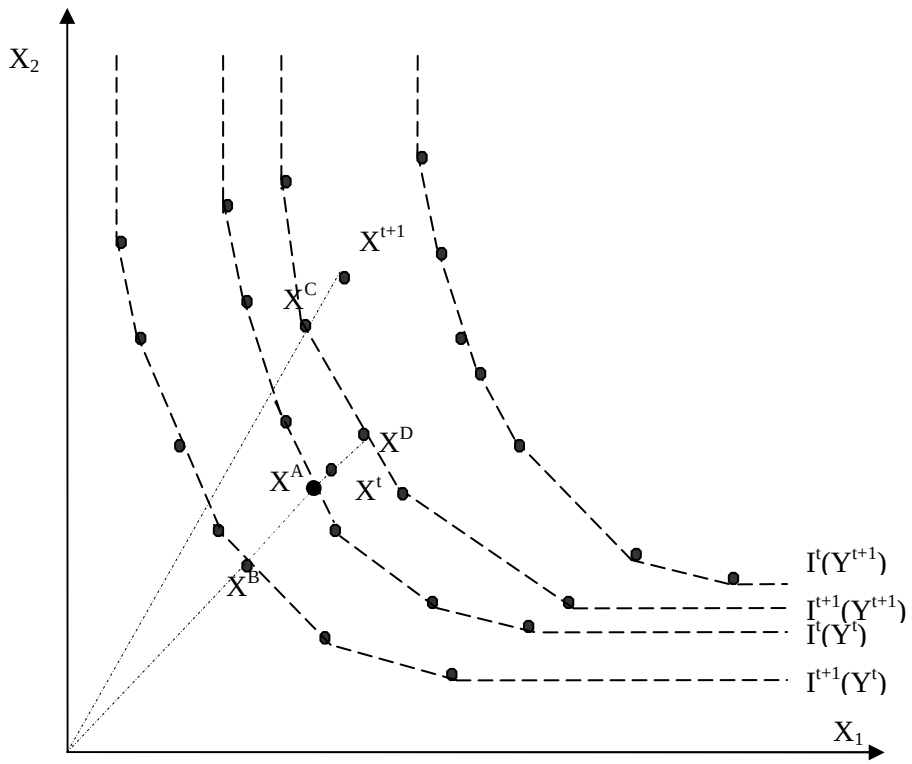

Figure 1- Productivity Effect

$$\overline{W}\left[\left(X^{t}-X^{B}\right)-\left(X^{t+1}-X^{C}\right)\right] \quad \textit{productivity effect}$$

$$=\overline{W}\left[\left(X^{A}-X^{B}\right)\right] \quad \textit{technical change} \qquad (10)$$

$$+\overline{W}\left[\left(X^{t}-X^{A}\right)-\left(X^{t+1}-X^{C}\right)\right] \quad \textit{efficiency change}$$

Technical change is measured by the distance X^{A} to X^{B}. As can be seen in Figure 1 this difference reflects the distance between the efficient boundaries in periods t and t+1, controlling for output level. Technical improvement occurs when

$X^B < X^A$. Such an improvement in the efficient boundary from t to t+1 has a positive effect on profit change from t to t+1, whereas with technical regress, $X^B > X^A$, and there will be a negative impact on profit change.

Moving to the efficiency change term in (10) we note that the distance from X^A to X^t reflects the inefficiency of the firm in period t and similarly the distance from X^C to X^{t+1} reflects the inefficiency of the firm in period t+1. Thus, as illustrated in (10) a decline in the input price weighted cost of inefficiency in period t+1, relative to the equivalent cost in period t, has a positive impact on profit change. In contrast, a rise in the input price weighted cost of inefficiency in period t+1 relative to that in period t would have a negative impact on profit change.

The activity effect in (9) can be further decomposed as follows:

$$\begin{aligned} &\overline{P}\left(Y^{t+1} - Y^t\right) - \overline{W}\left(X^C - X^B\right) \quad \textit{activity effect} \\ &= \overline{W}\left(X^D - X^C\right) \quad \textit{resource mix effect} \\ &- \overline{P}\left(Y^E - Y^{t+1}\right) \quad \textit{product mix effect} \\ &+ \overline{W}\left(X^B - X^D\right) - \overline{P}\left(Y^t - Y^E\right) \quad \textit{scale effect} \end{aligned} \tag{11}$$

The resource mix effect $X^D - X^C$ captures the impact on profits due to the change in the mix of inputs between period t and t+1 while keeping the output at the period t+1 level and also retaining efficiency in production (see Figure 1). When $X^D - X^C$ is positive, the change in resource mix reflects a movement of input usage to one which reduces costs, thereby improving allocative efficiency. Similarly, we can infer from Figure 2 the product mix effect as the change in output mix from Y^E to Y^{t+1}. Note that Y^E reflects the output mix of period t but its level is that resulting from using the efficient input level X^D in period t+1 to secure the output mix of period t.

Finally the scale effect consists of two components, the input scale effect and the output scale effect, thereby capturing the impact of scale change on the firm's profitability. From Figure 1, we note that to produce efficiently the output of period t, Y^t using the best practice technology available in period t+1, the input level needed is

X^B. In contrast when outputs change from Y^t to Y^{t+1}, while keeping the input mix and the technology constant to that of period t+1 the input required is X^D. The difference between X^B and X^D when positive means that efficient input level needed in constant technology has dropped as output changed from period t to t+1 and this has a positive impact on profit. As X^B and X^D have the same mix their difference simply reflect the difference in their scale size. In a similar manner, Y^t and Y^E have the same mix as can be seen in Figure 2 and their difference reflects the difference in their scale size. Y^t and Y^E are efficient output levels on t+1 technology using respectively input levels X^B and X^D already defined in Figure 1.

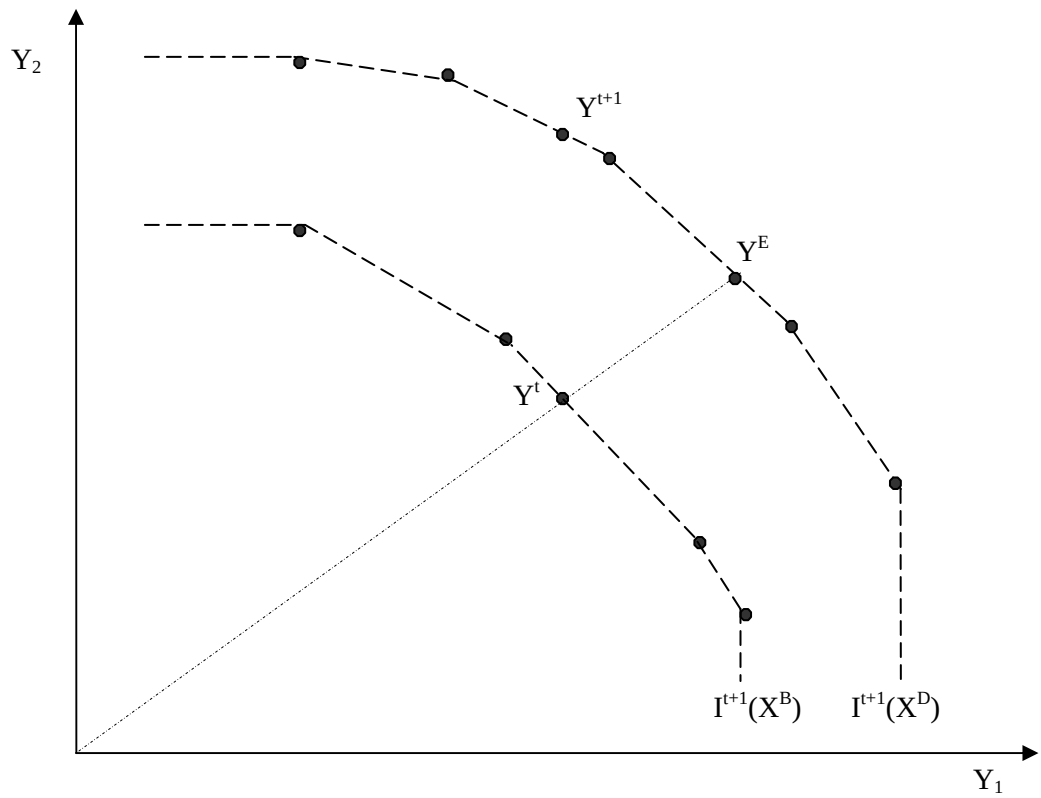

Figure 2- Activity Effect

2.3. Estimation with DEA

The second and third stage of the above profit decomposition requires the computation of the unobserved quantities $\left(X^A, X^B, X^C, X^D, Y^E\right)$. These unobserved input and output quantities can be estimated by means of the input and output distance functions as follows:

$$X^A = X^t * D_I^t\left(Y^t, X^t\right) \quad X^B = X^t * D_I^{t+1}\left(Y^t, X^t\right) \quad X^C = X^{t+1} * D_I^{t+1}\left(Y^{t+1}, X^{t+1}\right) \tag{12}$$
$$X^D = X^t * D_I^{t+1}\left(Y^{t+1}, X^t\right) \qquad Y^E = Y^t * D_O^{t+1}\left(\left(X^D, Y^t\right)\right)$$

The required distances and hence the quantities $\left(X^A, X^B, X^C, X^D, Y^E\right)$ as defined in (12) can be readily estimated using DEA. Let J, N, M and T denote, respectively, the total number of firms, inputs, outputs and time periods in the sample. Let ϕ denote a scalar, which represents the proportional contraction of the input vector, given the output vector and θ denote a scalar, which represents the proportional expansion of output vector, given the input vector. Let Y_j^t and X_j^t denote the $M \times 1$ output vector and the $N \times 1$ input vector respectively for the j-th firm in the t-th period $t = 1,2,...,T$. Let y^t and x^t denote respectively the $M \times J$ output matrix and the $N \times J$ input matrix in period t, containing the data for all the firms in the t-th period. The notation for period t+1 is defined similarly. We use the additional constraint $J1'\lambda = 1$ to allow for variable returns to scale technology. The reference technology for our DEA models is the sequential DEA technology which is defined in section 3. Sequential technology assumes that in any period t the technology of the previous periods remains feasible. By definition this technology does not allow for regress. Thus in period t the unobserved quantity X^A can be computed by the following linear programming problem:

$$\begin{aligned}
&\left[D_I^t\left(Y^t, X^t\right)\right]^{-1} = \phi^A = Min\,\phi \\
&subject\ to \\
&Y_j^t \le \sum_{k=1}^{k=t} \sum_{j=1}^{J} y_j^t \lambda_j^t \\
&\phi\ X_j^t \ge \sum_{k=1}^{k=t} \sum_{j=1}^{J} x_j^t \lambda_j^t \\
&\lambda \ge 0 \\
&J1'\lambda = 1
\end{aligned} \tag{13}$$

The variables $\lambda^k = \left(\lambda_1^k, \lambda_2^k, ..., \lambda_J^k\right)$ k=1…t whose optimal values are to be determined by the above model lead to the estimate the proportional reduction ϕ^A in X^t that would locate (X^t, Y^t) on the efficient frontier within the sequential, technology to period t. The unobserved quantity X^A for the firm having input output set (X^t, Y^t) is

thus $X^A = \phi^A X^t$. The unobserved quantity X^A is computed as $X^A = \phi^A X^t$ for each firm in the sample in period t.

The unobserved quantity X^B can be computed by solving the following linear programming problem:

$$
\begin{aligned}
&\left[D_I^{t+1}\left(Y^t, X^t\right)\right]^{-1} = \phi^B = Min\,\phi \\
&subject\ to \\
&Y_j^t \le \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} y_j^{t+1}\lambda_j^{t+1} \\
&\phi\ X_j^t \ge \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} x_j^{t+1}\lambda_j^{t+1} \\
&\lambda \ge 0 \\
&J1'\lambda = 1
\end{aligned}
\tag{14}
$$

The unobserved quantity X^B is computed as $X^B = \phi^B X^t$ for each firm (X^t, Y^t) in the sample in period t.

The unobserved quantity X^C can be computed using the following linear programming problem:

$$
\begin{aligned}
&\left[D_I^{t+1}\left(Y^{t+1}, X^{t+1}\right)\right]^{-1} = \phi^C = Min\,\phi \\
&subject\ to \\
&Y_j^{t+1} \le \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} y_j^{t+1}\lambda_j^{t+1} \\
&\phi X^{t+1} \ge \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} x_j^{t+1}\lambda_j^{t+1} \\
&\lambda \ge 0 \\
&J1'\lambda = 1
\end{aligned}
\tag{15}
$$

The unobserved quantity X^C is computed as $X^C = \phi^C X^{t+1}$ for each firm (X^{t+1}, Y^{t+1}) in the sample in period t.

The unobserved quantity X^D can be computed by the following linear programming problem:

$$
\begin{aligned}
&\left[D_I^{t+1}\left(Y^{t+1}, X^t\right)\right]^{-1} = \varphi^D = Min\,\varphi \\
&subject\ to \\
&Y_j^{t+1} \le \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} y_j^{t+1}\lambda_j^{t+1} \\
&\varphi X^t \ge \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} x_j^{t+1}\lambda_j^{t+1} \\
&\lambda \ge 0 \\
&J1'\lambda = 1
\end{aligned}
\tag{16}
$$

The unobserved quantity X^D is computed as $X^D = \varphi^D X^t$ for each firm (X^t, Y^{t+1}) in the sample in period t.

The unobserved quantity Y^E can be computed using (16) and the following linear programming problem:

$$
\begin{aligned}
&\left[D_o^{t+1}\left(Y^t, X^D\right)\right]^{-1} = \theta^E = Max\,\theta \\
&subject\ to \\
&\theta\ Y_j^t \le \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} y_j^{t+1}\lambda_j^{t+1} \\
&X_j^D \ge \sum_{k=1}^{k=t+1}\sum_{j=1}^{J} x_j^{t+1}\lambda_j^{t+1} \\
&\lambda \ge 0 \\
&J1'\lambda = 1
\end{aligned}
\tag{17}
$$

The unobserved quantity Y^E is computed as $Y^E = \theta^E Y^t$ for each firm (X^D, Y^t) in the sample in period t.

2.4. Profit Decomposition After Controlling for Quality

Since the water and sewerage companies have carried out substantial capital investment projects to improve drinking water quality and environmental standards, it is important to control for quality in our analysis. As the substantial drinking water quality and sewerage treatment improvements over the 1991-2008 period (Maziotis, Saal and Thanassoulis, 2009) have been in response to increasingly stringent environmental regulation, including EU directives, it is reasonable to assume that quality improvements are exogenously determined (Saal and Parker, 2000). Therefore, quality could effectively be included as an exogenous factor and is intended to control for changes over the assessment period in water quality,

environmental standards and characteristics that reflect differences between firms in terms of their operating environment (Stone & Webster Consultants, 2004). However, in more general contexts where regulation is not so tight it is possible for quality to be seen as a discretionary variable. Thus, differences in output quality between firms may result in legitimate differences in required inputs to produce a given quantity of output. Similarly, improving quality can also differentiate a firm's products, raising a consumers' willingness to pay and may also improve profitability, if the resulting increase in costs associated with such quality change does not exceed increases in revenues. This section therefore presents a profit decomposition approach which makes allowances for differences in output characteristics such as output quality between firms and across time.

As earlier the inputs are represented by a positive input quantity vector $X = (X_1, X_2, ..., X_N)$ where N denotes the total number of resources and the positive vector of input prices can be defined as $W = (W_1, W_2, ..., W_N)$. However, the positive vector of output quantities $Y = (Y_1, Y_2, ..., Y_M)$ where M denotes the total number of outputs is now separated into a non-negative vector of output for high quality $Y_h = (Y_{1,h}, Y_{2,h}, ..., Y_{M,H})$ and a non-negative vector of output for low quality $Y_l = (Y_{1,l}, Y_{2,l}, ..., Y_{M,L})$ where H and L denotes the total number of outputs for high and low quality respectively and we assume that $Y = Y_h + Y_l$ and that more inputs are required to produce a given amount of high quality output than to produce the same amount of low quality output. The positive vector of output prices $P = (P_1, P_2, ..., P_M)$ is similarly separated into a positive vector of output prices for high quality $P_h = (P_{1,h}, P_{2,h}, ..., P_{M,H})$ and a positive vector of output prices for low quality $P_l = (P_{1.l}, P_{2,l}, ..., P_{M,L})$ to reflect differences in output prices for quality between firms.

Therefore, given the assumptions that $Y = Y_h + Y_l$ and the output prices P_h and P_l the decomposition of profits into a quantity and price effect in equation (8) will become equation (8') as follows, using Bennet indicators, $\overline{P_h} = 1/2\left(P_h^{t+1} + P_h^t\right)$, $\overline{P_l} = 1/2\left(P_l^{t+1} + P_l^t\right)$, $\overline{W} = 1/2\left(W^{t+1} + W^t\right)$, $\overline{X} = 1/2\left(X^{t+1} + X^t\right)$, $\overline{Y_h} = 1/2\left(Y_h^{t+1} + Y_h^t\right)$, $\overline{Y_l} = 1/2\left(Y_l^{t+1} + Y_l^t\right)$:

$$\Pi^{t+1} - \Pi^{t} = [\overline{P}_h\left(Y_h^{\,t+1} - Y_h^{\,t}\right) + \overline{P}_l\left(Y_l^{\,t+1} - Y_l^{\,t}\right)] - \overline{W}\left(X^{\,t+1} - X^{\,t}\right) \quad \textit{quantity} \quad \textit{effect}$$

$$+ [\overline{Y}_h\left(P_h^{\,t+1} - P_h^{\,t}\right) + \overline{Y}_l\left(P_l^{\,t+1} - P_l^{\,t}\right)] - \overline{X}\left(W^{\,t+1} - W^{\,t}\right) \quad \textit{price} \quad \textit{effect} \tag{8'}$$

The difference between equations (8) and (8’) is in the output effect of the quantity effect and the output weights. Similarly in the price effect, the output component and corresponding weights change. The input effect components remain the same between (8) and (8’) as they are calculated using observed input quantities and input prices which have not changed. The quantity effect will now capture the contribution to profit changes from a change in output production of *high and low quality* and input usage, while the price effect will show the contribution to profit changes from a change in output prices for *high and low quality* and input prices.

Given that $Y = Y_h + Y_l$, and the output prices P_h, P_l the decomposition of the quantity effect into productivity and activity effect in equation (9) will now become equation (9’):

$$[\overline{P}_h\left(Y_h^{\,t+1} - Y_h^{\,t}\right) + \overline{P}_l\left(Y_l^{\,t+1} - Y_l^{\,t}\right)] - \overline{W}\left(X^{\,t+1} - X^{\,t}\right) \textit{quantity effect}$$

$$= \left[\overline{W}\left(X^{\,t} - X^{\,B'}\right) - \overline{W}\left(X^{\,t+1} - X^{\,C'}\right)\right] \quad \textit{productivi ty effect} \tag{9'}$$

$$+ \left[[\overline{P}_h\left(Y_h^{\,t+1} - Y_h^{\,t}\right) + \overline{P}_l\left(Y_l^{\,t+1} - Y_l^{\,t}\right)] - \overline{W}\left(X^{\,C'} - X^{\,B'}\right)\right] \quad \textit{activity effect}$$

The productivity effect is now calculated using observed input quantities and input prices, $\left(X^{\,t}, X^{\,t+1}, W^{\,t}, W^{\,t+1}\right)$ and unobserved quantities $\left(X^{\,B'}, X^{\,C'}\right)$. The results for the productivity effect will now be different from those obtained in equation (9). The quantities $X^{\,B'} = X^{\,t} * \phi^{B}$ and $X^{\,C'} = X^{\,t+1} * \phi^{C}$ where ϕ^{B} and ϕ^{C} are now optimal values as derived from models (14) and (15) respectively after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

The output side of the activity effect in equation (9’) now changes since it is calculated using the observed output quantities and prices, Y_h, Y_l, P_h, P_l. The activity effect now also reflects changes in output between high and low quality and the

efficient level of input needed to secure the output changes. The results for the activity effect in equation (9') will differ from those calculated in equation (9) since it uses the unobserved input quantities $\left(X^{B'}, X^{C'}\right)$ where estimates with DEA will need to include two output vectors, Y_h and Y_l instead of the aggregate vector Y, in the linear programming models (14) and (15). In an analogous manner, the results from the further decomposition of the productivity and activity effect into their components will also differ from those obtained in equations (10) and (11) since the recovery of the three unobserved input and output quantities needs to include two output vectors, Y_h and Y_l instead of the aggregate vector Y, in the linear programming models (15) to (17). The resource mix effect now reflects changes in the efficient mix of input usage to secure output of *high and low quality*, whereas the product mix effect changes in the output mix for *high and low quality*, and the scale effect reflects changes in the mix of output for *high and low quality* given efficient input usage.

The above modifications in the profit decomposition with adjustments for quality can be readily implemented if data for multiple output quality levels is available. However, in the UK water industry, all customers of a given water firm effectively pay the same price for water services regardless of output quality, as regulated water prices do not differentiate between quality of output. Moreover, given this regulatory practice, it is unsurprising that while total turnover data is available separately for water and sewerage services it is not disaggregated by quality of service. As a result, we do not in practice have different prices for high and low quality water and sewerage output types, even though we can observe quantity data reflecting differences in output quality. Hence, given that regulatory practice results in no quality related price differentials for a given company, we necessarily and appropriately proceed with the assumption that consumers pay the same price for high and low quality outputs. Thus, in our application we observe that $P = P_h = P_l$. It should be noted that in the general case the production of higher quality output may require more input of each type than the production of the same quantity of output of lower quality. Further, additional input types may be needed for producing higher quality output that are not necessary for producing output of lower quality. For example, different facilities and chemicals are needed at different stages of sewerage treatment, primary, secondary or tertiary. Prices for the different types of resources

used for output of different quality may also differ. These factors should be taken into account in the assessments being undertaken. Our own model implicitly allows for different levels of output quality requiring different levels of input but only for inputs that are common to high and low quality output. This is true by virtue of the fact that the DEA model sets the mix of outputs of high and low quality against the input bundle being used by each comparative unit. However, for the purpose of this study we make the assumption that no additional input types are needed for producing higher quality output and that prices of inputs are independent of the mix of output quality. This is consistent with previous studies of the UK water and sewerage industry by Saal & Parker (2000, 2001 and 2006) and Saal et. al (2007). However, in our empirical application in the linear programming models, we imposed the weight restriction that the production of high quality output is at least as resource intensive as the same quantity of output of low quality. We therefore modify our earlier notation to reflect this empirical characteristic of the English and Welsh water industry.

Given the single output price, $P = P_h = P_l$, profits decompose into a quantity and price effect as follows, using Bennet indicators, $\overline{P} = 1/2\left(P^{t+1} + P^t\right)$, $\overline{W} = 1/2\left(W^{t+1} + W^t\right)$, $\overline{X} = 1/2\left(X^{t+1} + X^t\right)$, $\overline{Y}_h = 1/2\left(Y_h^{t+1} + Y_h^t\right)$, $\overline{Y}_l = 1/2\left(Y_l^{t+1} + Y_l^t\right)$:

$$\begin{aligned}\Pi^{t+1} - \Pi^t = {} & \overline{P}[\left(Y_h^{\ t+1} - Y_h^{\ t}\right) + \left(Y_l^{\ t+1} - Y_l^{\ t}\right)] - \overline{W}\left(X^{t+1} - X^t\right) \quad \textit{quantity effect} \\ & + [\overline{Y}_h + \overline{Y}_l]\left(P^{t+1} - P^t\right) - \overline{X}\left(W^{t+1} - W^t\right) \quad \textit{price effect}\end{aligned} \tag{8''}$$

However, we need to underline that since $Y = Y_h + Y_l$ the results from the first stage of the profit decomposition in equation (8’’) will be exactly the same as in equation (8) since the decomposition of profits into a quantity and price effect is calculated using observed quantities and prices. Thus, equation (8’’) reveals that in the absence of differentiated prices for different output qualities, it is not possible to gain further information with regard to the overall quantity effect, even if we differentiate between different output qualities.

The difference between equations (8’’) and (8’) is in the weights used to evaluate the changes in the output side of the quantity effect since it is now calculated using the observed output prices, P, instead of P_h, P_l, and the output price of the

price effect, which now shows the contribution to profit changes from a change in output prices and input prices. The quantity effect now captures the contribution to profit changes from a change in output production of *high and low quality* and input usage, using as weights the observed output prices, P to evaluate the changes in the *high and low quality* output effect.

Moreover, given that $Y = Y_h + Y_l$, $P = P_h = P_l$, the decomposition of the quantity effect into the productivity and activity effects in equation (9') becomes:

$$\overline{P}[(Y_h^{t+1} - Y_h^t) + (Y_l^{t+1} - Y_l^t)] - \overline{W}(X^{t+1} - X^t) \quad \textit{quantity effect}$$

$$= [\overline{W}(X^t - X^{B'}) - \overline{W}(X^{t+1} - X^{C'})] \quad \textit{productivity effect} \qquad (9'')$$

$$+ [\overline{P}[(Y_h^{t+1} - Y_h^t) + (Y_l^{t+1} - Y_l^t)] - \overline{W}(X^{C'} - X^{B'})] \quad \textit{activity effect}$$

The difference between equations (9') and (9') is in the weights used to evaluate the changes in the output side of the activity effect since it is now calculated using the observed output prices, P, instead of P_h, P_l. Thus, we first emphasize, that the aggregate productivity effect obtained from a model differentiating output qualities is theoretically identical, regardless of whether we control for differences in output prices. In contrast, while the input side of the activity effect is theoretically identical to that obtained in equation (9), the reliance on quality undifferentiated output prices implies an alternative empirically observable weighting of the output side of the activity effect.

Moreover, the decomposition of the productivity effect into technical change and efficiency change given the assumption of quality undifferentiated output prices for different output qualities is now calculated using observed input quantities and input prices, $(X^t, X^{t+1}, W^t, W^{t+1})$ and unobserved quantities $(X^{B'}, X^{C'})$, which include two output vectors, Y_h and Y_l instead of the aggregate vector Y. Moreover, given that $Y = Y_h + Y_l$, $P = P_h = P_l$, the decomposition of the activity effect into resource mix, product mix and scale effect will become:

$$\overline{P}[(Y_h^{t+1} - Y_h^t) + (Y_l^{t+1} - Y_l^t)] - \overline{W}(X^{C'} - X^{B'}) \quad activity \quad effect$$

$$= \overline{W}(X^{D'} - X^{C'}) \quad resource\ mix\ effect \qquad (11'')$$

$$- \overline{P}[(Y_h^{E'} - Y_h^{t+1}) + (Y_l^{E'} - Y_l^{t+1})] \quad product\ mix\ effect$$

$$+ \overline{W}(X^{B'} - X^{D'}) - \overline{P}[(Y_h^t - Y_h^{E'}) + (Y_l^t - Y_l^{E'})] \quad scale\ effect$$

The scale effect captures the change in the efficient output levels for *high and low output quality* given efficient input usage. Also, given that $P = P_h = P_l$ the product mix effect will not reflect changes in the mix of output for *high and low quality* but only changes in the aggregate non quality differentiated mix of outputs. The resource mix effect and the input scale effect are calculated using observed input prices and unobserved input quantities $(X^{D'}, X^{C'}, X^{B'})$. Thus, the resource mix effect in particular is invariant to the assumption of quality undifferentiated output prices, in a model that allows for quality differentiated output quantities. The unobserved quantities $(X^{B'}, X^{C'}, X^{D'}, Y^{E'})$ in equation (11'') are recovered from the observed quantity vectors (X^t, Y_h^t, Y_l^t) and $(X^{t+1}, Y_h^{t+1}, Y_l^{t+1})$ by means of input and output distance functions and the linear programming models in (13)-(17) will still include two outputs, Y_h and Y_l.

3. Data and Empirical Implementation

Here we decompose the change in profits of English and Welsh water companies. Our model includes separate outputs for water and sewerage services, and the three inputs, capital, labour and other inputs. The data covers the period 1991-2008 for a balanced panel of 10 Water and Sewerage companies (WaSCs). Water connected properties and sewerage connected properties, Y_w and Y_s, are our outputs. They are drawn from the companies' regulatory returns to Ofwat. Water and sewage output prices were calculated as the ratio of the appropriate turnover in nominal terms, as available in Ofwat's regulatory returns, to measured output.

The first of three inputs, namely physical capital stock measure is based on the inflation adjusted Modern Equivalent Asset (MEA) estimates of the replacement cost of physical assets contained in the companies' regulatory accounts. However, as

periodic revaluations of these replacement cost values could create arbitrary changes in our measure of physical capital, we cannot directly employ these accounting based measures. Rather, we use real net investment is therefore taken as the sum of disposals, additions, investments and depreciation, as deflated by the Construction Output Price Index (COPI). Following Saal & Parker's (2001) approach, we have averaged the resulting year ending and year beginning estimates to provide a more accurate estimate of the average physical capital stock available to the companies in a given year.

We subsequently employed a user-cost of capital approach, to calculate total capital costs as the sum of the opportunity cost of invested capital and capital depreciation relative to the MEA asset values,. We constructed the price of physical capital as the user cost of capital divided by the above MEA based measure of physical capital stocks. The opportunity cost of capital is defined as the product of the weighted average cost of capital (WACC) before tax and the companies' average Regulatory Capital Value (RCV). The RCV is the financial measure of capital stock accepted by Ofwat for regulatory purposes. The WACC calculation is broadly consistent with Ofwat's regulatory assumptions and is estimated with the risk free return assumed to be the average annual yields of medium-term UK inflation indexed gilts. The risk premium for company equity and corporate debt was assumed to be 2% following Ofwat's approach at past price reviews. We also allowed for differences in company gearing ratios and effective corporate tax rates, which were calculated as the sum of aggregate current and deferred tax divided by the aggregate current cost profit before taxation. Finally, following the approach in Ofwat's regulatory current cost accounts, capital depreciation was the sum of current cost depreciation and infrastructure renewals charge.

Moving to our second input, labour, the average number of full-time equivalent (FTE) employees is available from the companies' statutory accounts. Firm specific labour prices were calculated as the ratio of total labour costs to the average number of full-time equivalent employees. Finally our third input, namely "Other costs" in nominal terms was defined as the difference between operating costs and total labour costs. Given the absence of data allowing a more refined break down of other costs, we employ the UK price index for materials and fuel purchased in purification and distribution of water, as the price index for other costs, and simply

deflate nominal other costs by this measure to obtain a proxy for real usage of other inputs. Finally, economic profits are calculated as the difference between turnover and calculated economic costs. Table 1 shows the aggregate statistics for our sample and all the data are expressed in real 2008 prices. To achieve this, we divided profits, turnovers, costs, output and input prices with the RPI index to express the changes in real terms setting the year 2008 as the base year.

As is well documented in past studies (see Saal & Parker 2000, 2001, Saal, Parker and Weyman-Jones, 2007, Maziotis, Saal and Thanassoulis, 2009), the English and Welsh water and sewerage companies have been obliged to carry substantial capital investment projects in order to improve water and sewerage quality and environmental standards. Thus, we feel it is important to include the impact of quality in our profitability, productivity and price performance measures. We therefore adjusted water and sewerage output for high and low water and sewerage quality respectively as follows.

Water quality is defined based on the data regarding drinking water quality and were drawn from the DWI's annual reports for the calendar years ending 1991-2007[2]. Following Saal and Parker (2001) water quality, Q_w, is defined as the average percentage of each WaSC's water supply zones that are compliant with key water quality parameters. Water supply zones are areas designated by the water companies by reference to a source of supply in which not more than 50,000 people reside. The drinking water quality can be defined either based on the sixteen water quality parameters or nine water quality parameters identified as being important for aesthetic, health reasons and cost reasons or based on the six water quality parameters identified as being indicative of how well treatment works and distribution systems are operated and maintained. Due to changes in some of the drinking water quality standards and the new regulations, the DWI report for 2005 no longer included the two quality indices that compared companies' compliance for the sixteen or nine water quality parameters with the average for England and Wales. So we decided to

[2] The DWI provides quality data based on calendar years, while all other information employed in this paper is based on fiscal years ending March 31st. We note this inconsistency in the data, but emphasize that the reported years overlap each other for 9 months. Thus, the year end to year end estimates of quality change obtained from the DWI data provide consistent estimates of quality change by the water companies, at a fixed point 9 months into each fiscal year.

base the drinking water quality on the six water quality parameters[3] that Ofwat also employs in its assessment. The parameters reflect how well treatment works and distribution systems are operated and maintained (Ofwat, 2006).

High drinking water quality, $Q_{w,h}$, is defined as the average percentage of each WaSC's water supply zones that are compliant with these six water quality parameters. Low drinking water quality $Q_{w,l}$ is defined as the average percentage of each WaSC's water supply zones that are not compliant with these six water quality parameters. The water output for high quality, $Y_{w,h}$, is calculated as the product of the water connected properties and high drinking water quality, $Y_{w,h} = Y_w Q_{w,h}$. The water output for low quality, $Y_{w,l}$ is defined as the product of the water connected properties and low drinking water quality, $Y_{w,l} = Y_w Q_{w,l} = Y_w (1 - Q_{w,h})$. Note that the sum of water output for high and low quality is equal to the water output, $Y_w = Y_{w,h} + Y_{w,l}$. The water output price is the same for high and low quality and it is defined as the ratio of water total turnover in nominal terms to the sum of water output for high and low quality.

Sewerage quality, Q_s, is defined based on the data regarding the percentage of connected population for which sewage receives various types of treatment, zero, primary, secondary or higher treatment. The sewage treatment data were taken from *Waterfacts* for the period 1990-91 to 1995-96 and the companies' regulatory returns for the fiscal years 1996-97 to 2007-08. We henceforward refer to data based on the ending year of the fiscal years. High sewerage treatment quality, $Q_{s,h}$, is defined as the percentage of connected population receiving at least secondary or higher sewerage treatment, while low sewerage treatment quality, $Q_{s,l}$, is defined as the percentage of connected population receiving zero or primary sewerage treatment. The sewerage output for high quality, $Y_{s,h}$, was calculated as the product of sewerage connected properties and the percentage of connected population receiving at least secondary or higher sewerage treatment, $Y_{s,h} = Y_s Q_{s,h}$. The sewerage output for low quality, $Y_{s,l}$ was calculated as the product of sewerage connected properties and the

[3] The six water quality parameters, which form the Operational Performance Index (OPI) are iron, manganese, aluminium, turbidity, faecal coliforms and trihalomethanes.

percentage of connected population receiving zero or primary sewerage treatment, $Y_{s,l} = Y_s Q_{s,l}$. Note that the sum of sewerage output for high and low quality is equal to the sewerage output, $Y_s = Y_{s,h} + Y_{s,l}$. The sewerage output price was the same for high and low quality and it was defined as the ratio of sewerage total turnover in nominal terms to the sum of sewerage output for high and low quality. Finally, Table 1 shows the aggregate statistics for our sample and all the data are expressed in real 2008 prices. To achieve this, we divided profits, turnovers, costs, output and input prices with the RPI index to express the changes in real terms setting the year 2008 as the base year.

Since our sample includes 10 WaSCs over an 18 year period, 1991-2008, we decided to modify the estimation with DEA as follows in order to deal with the small number of observations each year. Tulkens & Vanden Eeckaut (1995) proposed four different production sets using DEA in a panel data framework, the contemporaneous, sequential, intertemporal frontiers and window analysis. A contemporaneous production set assumes the construction of a reference production set at each point in time t, from the observations made at that time only. A sequential production set allows the current period technology set to be constructed from data of all the companies in all years prior to and including the current period. Thus, technologies in previous periods are “not forgotten” and remain available for adoption in the current period and therefore technical regress is not allowed. An intertemporal production set assumes the construction of a single production set from the observations made throughout the whole observation period. Window analysis is a moving average pattern of analysis, in which each unit in each period is treated as if it is a different unit. The performance of a unit is compared with its performance in other periods, in addition to comparing it with the performance of other units in the same period.

Drawing on the foregoing and the sequential technology in particular, the reference technology for our DEA models is as follows. We have a balanced panel of ten observations (firms) for each year over 1991-2008. We decided to pool the data from 1991-1994 together in order to increase the number of observations from ten to forty. The first sub-panel includes periods $\{1991, 1992, 1993, 1994\}$ and we use the observations from these years as a cross section to construct our reference technology and we refer to the corresponding frontier as our t = 1994 frontier. The second sub-

panel contains periods $\{1991, 1992, 1993, 1994, 1995\}$ and we use the frontier constructed using the 1991-1995 data as our t+1 = 1995 frontier and so on until the last sub-panel which is actually the entire panel and includes periods $\{1991, 1992, 1993, 1994, ..., 2008\}$. Thus in essence we use the sequential technology of Tulkens & Vanden Eeckaut (1995) except that our starting technology is the four-year period 1991-1994.

4. Empirical Results

Before turning to our results, we first consider trends in aggregate WaSC turnover, costs and profits as reported at Table 1 where aggregate statistics for our sample are displayed. Focusing on economic profits, we notice that there was a substantial increase in aggregate profits over the period 1994 to 2000, from 859.1 million pounds to 1,299.70 million pounds, reaching their highest level in 2000 over the entire period of study. In 2001, the first year of tightened price caps following the 1999 price review, the companies were obliged to reduce the prices charged to customers, and there was a substantial decline in aggregate profits and the industry made economic losses except for the year 2006, when the 2004 price review introduced new looser price caps. As far as aggregate turnover was concerned, it increased from 7,124.6 million pounds to 7,908.2 million pounds over the years 1994-2000 but it significantly decreased in 2001 at the level of 7,162.9 million pounds. Over the period 2001-2008, the aggregate turnover increased significantly from 7,162.9 to 8,494.6 million pounds. Moreover, economic costs increased from 6,267.3 to 8,748 million pounds over the period 1994-2008 showing the highest level of increase over the period 2001-2008. Thus, in aggregate, the increase in turnover after 2001 was outstripped by even greater increases in economic costs resulting in economic loss for the water and sewerage companies at the last year of our sample.

	Units	1994	2000	2001	2005	2006	2008
Economic Profit	£000000s (2008)	859.1	1,299.70	-186	-227.1	386.4	-253.5
Revenues	£000000s (2008)	7,126.4	7,908.2	7,162.9	7,491.9	8,198.2	8,494.6
Total Economic Costs	£000000s (2008)	6,267.3	6,608.4	7,349.0	7,718.9	7,811.8	8,748.0
Water Connected Properties	000s	16,665	18,304	19,302	19,821	19,972	20,061
High Quality Adjusted Water Connected Properties[1]	000s	15,101	17,237	18,412	19,083	19,297	19,442
Low Quality Adjusted Water Connected Properties[2]	000s	1,564	1,067	890	738	676	619
Sewerage Connected Properties	000s	21,298	22,123	22,274	23,017	23,456	23,795
High Quality Adjusted Sewerage Connected Properties[3]	000s	16,963	19,239	20,939	22,647	23,186	23,072
Low Quality Adjusted Sewerage Connected Properties[4]	000s	4,335	2,884	1,335	370	270	723
Capital	£000000s (2008)	192,295	206,597	208,168	213,253	214,362	216,918
Number of employees	FTE	38,125	29,685	27,854	27,197	27,554	29,524
Other Inputs	£000000s (2008)	999.5	970.1	958.6	824.6	819.3	781.4
Avg. Price for a Quality Adjusted Water Connected Property	£s (2008)	219.01	198.75	176.9	178.06	193.87	204.35
Avg. Price for a Quality Adjusted Sewerage Connected Property	£s (2008)	229.87	229.5	175.07	168.01	178.43	185.7
Price for Capital	£s (2008)	0.017	0.019	0.023	0.024	0.024	0.028
Price for Labour	£000s (2008)	32.17	33.78	33.46	37.63	37.92	36.85
Price of Other Inputs[5]	(2008)	0.74	0.767	0.762	0.889	0.957	1

1. Calculated as the product of water connected properties and the average percentage of each WaSC's water supply zones fully compliant with key drinking water quality parameters
2. Calculated as the product of water connected properties and the average percentage of each WaSC's water supply zones not compliant with key drinking water quality parameters
3. Calculated as the product of sewerage connected properties and the percentage of population receiving at least secondary or higher sewerage treatment
4. Calculated as the product of sewerage connected properties and the percentage of population receiving zero or primary treatment
5. UK price index for materials and fuel purchased in purification and distribution of water

Table 1- Aggregate Profits, Revenues, Costs, Outputs, and Inputs

4.1. Quality Unadjusted Results

Table 2 displays cumulative profit change and the drivers of profit change defined in equations (8) to (11) for the entire 1994-2008 period and the regulatory sub-periods 1994-2000, 2000-2005 and 2005-2008, but without making any allowances for any differences in the quality of outputs. Over the entire 1994-2008 period, the quantity effect, efficiency change, resource mix and scale effect contributed positively to profit changes, while the price effect, technical change and product mix effect contributed negatively to profit changes. Focusing on aggregate profit change, profits reduced by 1,112.6 million pounds over the period 1994-2008, which was the result of significant aggregate profit decrease during the years 2000-2008 and significant aggregate profit increase during the years 1994-2000. In aggregate, profits increased by 440.6 million pounds during the years 1994-2000 and reduced by 1,526.8 million pounds during the years 2000-2005 and 26.4 million pounds during the years 2005-2008.

	1994-2008	1994-2000	2000-2005	2005-2008
Profit change	-1,112.6	440.6	-1,526.8	-26.4
Quantity effect	1,335.7	538.8	676.4	120.5
Output effect	1,080.4	482.6	413.7	184.1
Input effect	255.3	56.2	262.6	-63.6
Productivity	1,155.9	589.7	506.0	60.2
Technical Change	1,041.5	609.3	348.6	83.6
Efficiency Change	114.4	-19.6	157.4	-23.4
Activity effect	179.8	-50.9	170.4	60.3
Resource Mix	939.2	147.5	355.7	436.0
Product Mix	-2.1	47.1	-90.5	41.3
Scale Effect	-757.2	-245.5	-94.8	-417.0
Price Effect	-2,448.3	-98.1	-2,203.2	-146.9
Output Price Effect	287.7	299.2	-830.0	818.6
Input Price Effect	-2,736.00	-397.33	-1,373.14	-965.53

Table 2- Cumulative Profit Change and Its Decomposition (2008 pounds, millions)

Looking at the first stage of profit decomposition, where profit change was decomposed into a quantity and price effect (see equation 8), we conclude that over the entire period, the negative effect on cumulative profit change was attributed to a significant negative price effect which outstripped the positive quantity effect. The cumulative impact of the price effect led to a

2,448.3 million pounds reduction in profits offsetting the cumulative impact of the quantity effect which resulted in a 1,335.7 million pounds increase in profits.

At the first stage of profit decomposition, the price effect can be further decomposed into an output price and input price effect and the quantity effect into an output and input effect. During the years 1994-2008, output prices increased profits by 287.7 million pounds, however, greater increases in input prices contributed negatively to profit changes by 2,736 million pounds resulting in the overall negative entire price effect. Focusing on the sub-periods of our sample, we conclude that during the years 1994-2000, covering the end of the first price review after privatization and the entire 1995-2000 period covered by the 1994 price review, there was a small increase in output prices contributing positively to profit changes, 299.2 million pounds. However, substantial increases in input prices counteracted this as they reduced profits by 397.33 million pounds. Furthermore, the dramatically tightened 1999 price review obliged the companies to reduce their output prices and continuing increases in input prices resulted in a negative overall price effect which contributed negatively to profit changes, 2,203.2 million pounds between 2000 and 2005. During the years 2005-2008, output prices increased significantly, providing evidence that the 2004 price review was relatively loose and thereby contributing positively to profit changes, 818.6 million pounds, whereas increases in input prices moderated and reduced profits by 965.53 million pounds resulting in a small overall negative price effect.

In contrast to the high negative price effect, the overall positive quantity effect was attributed to a substantial increase in outputs contributing 1,080.4 million pounds to profit changes. Significant aggregate output increases occurred during the years 1994-2000 and 2000-2005, contributing positively to profit changes, 482.6 and 413.7 million pounds respectively, whereas small aggregate increase in outputs during the years 2005 -2008 increased profits by 184.1 million pounds. Focusing on aggregate input effect, the input effect increased profits by 255.3 million pounds over the period 1994-2008, which was the result of significant aggregate input usage reductions during the years 1994-2000 and 2000-2005 and small aggregate input usage increase during the years 2005-2008. In aggregate, input usage reductions increased profitability by 56.2 and 262.6 million pounds respectively during the years 1994-2000 and 2000-2005 and input usage increases reduced profitability by 63.6 million pounds during the

years 2005-2008. It is worth mentioning that during the years 1994-2000 small increases in aggregate profits were attributed to the substantial positive quantity effect which outstripped the negative price effect. However, the magnitude of the negative price effect, derived from both input and output price effects, during the years 2000-2005 resulted in a dramatic deterioration in economic profitability between 2000 and 2005, despite a substantial positive quantity effect amounting to 676.4 million pounds.

Looking at the second stage decomposition we see in Table 2 that the positive quantity effect over the entire period was attributed to a significant positive productivity effect and a small but positive activity effect. During the years 1994-2008, the productivity effect increased profits by 1,155.9 million pounds, whereas the activity effect increased profits by 179.8 million pounds. Almost the entire productivity effect can be explained by technical change which contributed positively to profit change 1,041.5 million pounds, while the contribution of increased efficiency only amounted to 114.4 million pounds. In aggregate, the productivity effect significantly increased profits by 589.7 and 506 million pounds respectively during the years 1994-2000 and 2000-2005, while 60.2 million pounds contribution during the years 2005-2008 was much more modest.

Focusing on the components of productivity effect in Table 2, technical change was positive during the years 1994-2008, increasing profits by 1,041.5 million pounds, showing the highest magnitude of increase during the years 1994-2000 and 2000-2005, 609.3 and 348.6 million pounds, respectively. In contrast to the substantial positive technical change effect, efficiency change was small and negative during the years 1994-2000 and 2005-2008, but did substantially increase profits by 157.4 million pounds during the years 2000-2005.

Focusing on the decomposition of the activity effect in Table 2, it is concluded that in aggregate the positive activity effect was mainly explained by substantial positive resource mix which was unfortunately largely offset by the very substantial negative scale effect as well as the quite small negative product mix effect. Over the whole period, the resource mix effect contributed 939.2 million pounds to increased profits, whereas the scale effect and product mix effect reduced profits by 757.2 and 2.1 million pounds respectively. The resource mix effect increased significantly over the entire period and especially during the years 2000-2005 and 2005-2008 suggesting movement to a more cost efficient allocation of resources more in line

with relative factor prices. Thus, over the whole period, capital input increased by 12.8%, whereas labour input decreased by 22.56% as can be seen in Table 1, indicating that the water industry became more capital-intensive and less labour-intensive. Moreover, the scale effect, resulting from respective increases in water and sewerage outputs of 20.37%, and 11.72%, did not lower costs and reduced profits significantly during the years 1994-2000 and 2005-2008 by 245.5 and 417 million pounds respectively. However, the negative impact of the scale effect declined during the years 2000-2005. Changes in the mix of outputs, the production of more output for water services than sewerage services increased profits by 47.1 and 41.3 million pounds respectively during the years 1994-2000 and 2005-2008 but decreased profits significantly by 90.5 million pounds during the years 2000-2005.

Overall, relating the results from the decomposition of profits into several factors in Table 2 with the regulatory cycle, we conclude that during the years 1994-2000 when price caps were tightened after the 1994 price review, profits increased. This increase in aggregate profitability was attributed to the positive cumulative quantity effect, and still increasing output prices which just offset substantial increases in input prices. There were also significant improvements in productivity mainly attributable to technical change, indicating that the most productive companies significantly improved their performance. Furthermore, there was evidence that changes in the mix of inputs and outputs had a positive impact on aggregate profitability until 2000. During the years 2000-2005 when profits substantially decreased, the cumulative impact of price effect as captured by a significant reduction in output prices due to the tightened 1999 price review and a high increase in input prices offset the positive quantity effect. However, there were still substantial productivity improvements attributed to both technical change and increased efficiency, indicating that both the most productive and the less productive firms had strong incentives to improve their productivity in order to regain economic profitability. Moreover, adjusting to a more cost efficient input mix also appeared to have lowered costs and increased profits. Finally, during the years 2005-2008, when profits reduced very slightly, this was explained by a positive cumulative impact of the quantity effect, and substantial gains in output prices, which were nonetheless almost completely offset by large increases in input prices. Digging deeper into the quantity effect reveals that changes in the mix of input, outputs and technical change had a positive impact on aggregate profitability. However,

no improvements in efficiency change and increases in the scale of operations significantly reduced aggregate profitability.

4.2. Results After Controlling for High and Low Quality

We turn our discussion now to the results from cumulative profit change and its decomposition for the periods 1994-2000, 2000-2005 and 2005-2008 when we allow for differences in the quality of output. As explained in sections 2.2 and 2.3, the sum of water output of high and low quality was equal to the quality unadjusted water output and the sum of sewerage output of high and low quality was equal to the quality unadjusted sewerage output. The output price was the same regardless of the level of quality, high or low. Therefore, the results from the first stage of the profit decomposition in Table 3, the quantity and price effect will be exactly the same as those in Table 2, when quality is not included in our analysis. Differences between the quality unadjusted results and the results after controlling for high and low quality relate to the decomposition of the quantity effect into a productivity and activity effect, e.g. in the second and third stage of the profit decomposition.

Table 3 further depicts the results from the decomposition of the output effect into high quality and low quality output effect. The results indicate that over the whole period the water and sewerage companies moved to the production of more high quality of output than low quality of output contributing positively to the overall output effect and therefore to profit changes. Over the whole period, high quality outputs increased profits by 2,067.1 million pounds. Significant aggregate high quality output increases occurred during the years 1994-2000 and 2000-2005, contributing positively to profit changes, 902.3 and 1,015.5 million pounds respectively, whereas small aggregate increases in high quality outputs during the years 2005-2008 increased profits by 149.3 million pounds. Focusing on the aggregate low quality output effect, it decreased profits by 986.6 million pounds over the period 1994-2008, which was the result of significant aggregate low quality output reductions during the years 1994-2000 and 2000-2005 and small aggregate low quality output increase during the years 2005-2008. In aggregate, low quality output reductions decreased profitability by 419.8 and 601.7 million pounds respectively during the years 1994-2000 and 2000-2005 and low quality output increases increased profitability by 34.9 million pounds during the years 2005-2008.

	1994-2008	1994-2000	2000-2005	2005-2008
Profit change	-1,112.6	440.6	-1,526.8	-26.4
Quantity effect	1,335.7	538.8	676.4	120.5
Output effect	1,080.4	482.6	413.7	184.1
High Quality Output Effect	2,067.1	902.3	1,015.5	149.3
Low Quality Output Effect	-986.6	-419.8	-601.7	34.9
Input effect	255.3	56.2	262.6	-63.6
Productivity	1,089.5	563.5	457.4	68.6
Technical Change	989.4	556.1	321.6	111.8
Efficiency Change	100.0	7.4	135.8	-43.2
Activity effect	246.2	-24.7	219.0	52.0
Resource Mix	1,176.1	275.6	520.8	379.7
Product Mix	30.4	-60.9	81.8	9.5
Scale Effect	-960.3	-239.5	-383.5	-337.3
Price Effect	-2,448.3	-98.1	-2,203.2	-146.9
Output Price Effect	287.7	299.2	-830.0	818.6
Input Price Effect	-2,736.00	-397.33	-1,373.14	-965.53

Table 3- Cumulative High And Low Quality Adjusted Profit Change and Its Decomposition (2008 pounds, millions)

The positive quantity effect over the entire period can be entirely attributed to the significant positive productivity which offset the small but positive activity effect. During the years 1994-2008, the productivity effect substantially increased profits by 1,089.5 million pounds, whereas the activity effect increased profits by 246.2 million pounds. The positive productivity effect can be entirely attributed to technical change which increased profits by 989.4 million pounds and offset the small but positive efficiency change which increased profits only by 100 million pounds. Focusing on the components of the productivity effect, technical change was large and positive during the years 1994-2000 and 2000-2005, increasing profits by 556.1 and 321.6 million pounds respectively, whereas it slightly increased profit changes for the years 2005-2008, 111.8 million pounds. In contrast to the substantial positive technical change, efficiency change was positive during the years 1994-2000 and 2000-2005, increasing profits by 7.4 and 135.8 million pounds respectively, while it remained negative during the years 2005-2008 reducing profits by 43.2 million pounds.

Focusing on the decomposition of the activity effect reveals that its relatively low magnitude is the result of the large but contrasting impacts of the resource mix and scale effects. Thus, the aggregate positive activity effect was mainly explained by a high positive resource mix

and small product mix effect, which outstripped a very large and substantial negative scale effect. Over the whole period, the resource mix and product mix effect substantially contributed to increased profits by 1,176.1 and 30.4 million pounds respectively, whereas scale effect reduced profits by 960.3 million pounds. The resource mix effect contributed significantly to profit change over the entire period and especially after 2000 indicating that there was a steady shift to a more capital intensive resource allocation that was more cost effective given observed input prices. However, the scale effect did not lower costs and reduced profits significantly during each of the sub-periods detailed in Table 3. Thus, our results suggest that the substantial savings attributed to a more cost efficient allocation of resources, as measured by the resource mix effect, were lost due to the excessive scale of the WaSCs and several mergers during the period when the WaSCs absorbed water only companies (WoCs). This result is consistent with previous evidence with regard to the presence of diseconomies of scale for the WaSCs (Stone & Webster Consultants, 2004, Saal and Parker, 2000, Bottaso and Conti, 2009, Saal et al, 2007).

We moreover note that changes in the mix of outputs increased profits significantly by 81.8 and 9.5 million pounds respectively during the periods 2000-2005 and 2005-2008 but decreased profits by 60.9 million pounds during the period 2000-2005. However, given the lack of quality based price data in our empirical model, it must be noted that this effect only captures the impact of the change in the relative output of water services in comparison to sewerage services. Thus, as can be seen from Table 1, over the whole period there was an increase in output for water services of 20.37%, while the output for sewerage services increased by 11.72%.

Looking at the two types of profit decomposition, it is concluded that without and after controlling for quality there were differences in the results. In both cases, the major determinant on the negative aggregate profitability is explained by the overall negative price effect which outstripped the overall positive quantity effect. However, the difference in the results from the two types of profit decomposition is on the magnitude of the productivity and activity effect and their components on the quantity effect. After controlling for quality, the impact of the productivity effect on the aggregate profitability reduced from 1,155.9 to 1,089.5 million pounds, whereas the impact of the activity effect on profit change significantly increased, from 179.8 to 246.2 million pounds. In particular, after controlling for quality, technical change still remained

the major determinant of productivity effect and consequently on the quantity effect, however, its magnitude decreased from 1,041.5 to 984.4 million pounds. Also, efficiency change decreased from 114.4 to 100 million pounds but it became now positive for the period 1994-2005. Looking at the components of the activity effect, it is concluded that after controlling for quality, over the entire period the resource mix and product mix effect increased by 236.9 and 28.3 million pounds respectively, whereas the magnitude of the scale effect increased even further, by 203.1 million pounds. It is worth mentioning that the bigger changes in the components of the activity effect occurred during the years 2001-2005. After controlling for quality, the resource mix, product mix and scale effect increased by 165.1, 172.3 and 288.7 million pounds respectively, increasing their impact on quantity effect and therefore, on aggregate profitability. The bigger activity effect is attributed to the following factors. Firstly, given the lack of differentiated quality output prices, the resource mix effect captures changes in the efficient mix of input usage to secure output of *high and low quality*. Also, the product mix effect does not reflect changes in the mix of output for high and low quality but only changes in the aggregate non quality differentiated mix of outputs, ie outputs for water and sewerage services. Finally, the scale effect captures the change in the efficient output levels for *high and low output quality* given efficient input usage.

5. Conclusions

In this study, we firstly applied an input oriented profit decomposition approach following the approach of De Witte & Saal (2009). Then, we make allowances for differences in the quality of output, by decomposing the output effect into high and low quality output effect. We decompose profit changes into various factors such as quantity and price effect, technical change, efficiency change, resource mix, product mix and scale effect, without and after controlling for quality. We also adapted the sequential DEA approach of Tulkens and Vanden Eeckaut (1995) so that we could compute profit decomposition even when the number of observations is extremely limited. We applied our profit decomposition approaches to the Water and Sewerage Companies (WaSCs) in England and Wales over the period 1991-2008. The profit decomposition approaches, without and after controlling for quality, demonstrated differences in the results with respect to the magnitude of the productivity and activity effect.

The results before and after controlling for differences in the quality of outputs suggested that over the whole period the main source of negative profit change was driven by the substantial negative price effect which outstripped the positive quantity effect. The overall positive quantity effect was attributed to substantial increases in outputs and a small but positive input effect. On one level, our analysis demonstrated that the positive output effect was attributed to a substantial increase in high quality outputs which outstripped the negative low quality output effect. However, our DEA based decomposition allowed a deeper analysis, which demonstrates that the major determinants on the quantity effect were technical change, although its magnitude substantially reduced during the years 2005-2008, the resource mix effect, and the negative scale effect. In contrast, efficiency change and the product mix effect were found to have a small impact on profit change. On balance we would conclude that the substantial savings won by the WaSCs through capital labour substitution and technical change were lost due to the negative effects associated with increasing scale. After controlling for quality, the magnitude of productivity effect slightly decreased whereas the magnitude of activity effect substantially increased. This is attributed to the fact that even if quality differentiated output prices do not exist, the resource mix effect captures changes in the efficient mix of input usage to secure output of *high and low quality*, whereas the product mix effect reflect changes in the mix of output for water and sewerage services, and the scale effect captures the change in the efficient output levels for *high and low output quality* given efficient input usage.

Our methodological discussion suggests that a quality based decomposition of the output vector will reveal superior unbiased estimates of the underlying technology and costs of a firm even with the assumption of undifferentiated output prices. Thus, the differentiation of output quantities by quality does allow an alternative decomposition of the aggregate quantity effect, which is arguably superior because estimated technologies and distances will better reflect how quality influences input requirements. Furthermore, even if quality differentiated output prices are not available, the decomposition of the productivity effect and its components, technical change and efficiency change, the resource mix effect and the input price effect are invariant, in a model that allows for quality differentiated output quantities. Moreover, it is clear that future applications in which quality differentiated output prices are available, would allow researchers to not only better model the impact of quality quantity changes on costs, but would also allow researchers to impact how quality related price changes impact firm revenues and hence profits.

Thus, our theoretical model demonstrates a straight forward and integrated methodology that researchers could employ to conduct a fully integrated analysis of the impact of output quality change on profitability, thereby addressing a methodological issue not previously considered in the profit change literature, and which should be generally applicable.

We also note that our study has illustrated that the application of a profit decomposition methodology facilitates a backward-looking approach that allowed conclusions to be drawn with regard to the impact of price cap regulation on the financial performance of the regulated companies when the number of observations was extremely limited. This methodology should enable regulators and regulated companies to identify the sources of profit variation and aid them to evaluate firstly the effectiveness of the price cap scheme and the performance of the regulated companies. Also, profit decomposition enables the regulator to identify those sources of profits that can be passed along to the consumers e.g. any improvements in productivity that could pass to the consumers in terms of lower output prices. Our methodology can also be used by the regulated companies to identify the determinants of their profit changes and improve future performance, thereby leading to future profit gains Thus, we also emphasize the relevance of profit decomposition methodology in regulated industries as well as more generally.

Finally, the results from the two types of profit decomposition have significant policy implications for the regulated UK water and sewerage industry and can be summarized as follows. Firstly, the substantial capital investment programs carried output by the water and sewerage companies since privatization leaded to the production of high quality output and the reduction of low quality output. Secondly, significant productivity improvements which contributed positively to profit changes were mainly attributed to technical change, whereas gains in efficiency were small. This finding is consistent with Cave's review (2009) findings which suggested that since privatization the main driver on productivity growth for the UK water and sewerage sector was attributed to technical change, however, our findings also suggest that technical was falling over time. Finally, the results from the profit decompositions showed that the resource mix effect was significantly large and positive over the whole period indicating that the water and sewerage industry moved to a cost efficient allocation of resources by substituting labour with capital and therefore contributing positively to profits. However, any substantial savings occurred by the resource mix effect were lost due to excessive mergers. The scale effect

was negative over the whole period and substantially increased after 2000 indicating that the mergers occurred in 2000/01 had a negative impact on aggregate economic profitability. Therefore, this finding suggests that mergers were not profitable for WaSCs which is in contrast to Cave's review (2009) recommendations which suggested further mergers in the UK water and sewerage industry. We strongly believe that this finding is important as it will allow further analysis on developing methodologies to explore the issue of economies of scale and scope and conclude about the most economically efficient structure and the existence of vertical integration economies in the UK water and sewerage industry.

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