# A PANEL BASED PROFIT DECOMPOSITION TECHNIQUE TO IDENTIFY THE 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, when the number of observations is limited. We follow the input oriented profit decomposition approach of De Witte & Saal (2010) and by making allowances for differences in the quality of output, we decompose 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. 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 and output mix. 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

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 enables regulators and regulated companies to identify the sources of profit variation such as price effects, productivity effects, changes in the mix of resources, outputs and the scale of operations and aid them to evaluate firstly the effectiveness of the price cap scheme and the performance of the regulated companies. Secondly and more significantly, 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. Moreover, 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.

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

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. However, none of the above studies include any exogenous factors in the profit decomposition analysis. Especially, since the UK water and sewerage industry is characterised by high capital investment programs to improve drinking water quality and environmental standards and past research has demonstrated that water and sewerage quality do significantly impact productivity and price performance measures across firms and over time (see Saal & Parker, 2001 and Maziotis, Saal and Thanassoulis, 2009), the inclusion of exogenous characteristics like quality in a profit decomposition analysis is therefore important.

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 follow the input oriented profit decomposition approach of De Witte & Saal (2010) and by making allowances for differences in the quality of output, we decompose the output effect into high quality and low quality output effect. Profits decompose 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. Furthermore, as in previous studies (see Grifell and Lovell (1999)), our sequential DEA technique allows measurement of the productivity and the activity effect and their components where the number of observations is extremely limited. Finally, we provide a discussion of results from the profit decomposition approach on Water and Sewerage Companies (WaSCs) in England and Wales over the period 1991-2008 and the policy implications for the UK water and sewerage industry.

This paper unfolds as follows. Section 2 discusses the concept of distance functions. It includes an analysis of the decomposition of profits into its various components and the Data Envelopment Analysis (DEA) technique in order to estimate the components of the profit decomposition. 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:

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

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

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:

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

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 $Y^t \in O^t(Y^t), D_O^t(Y^t, X^t) \leq 1$ and for $Y^t \in I^t(X^t), D_O^t(Y^t, X^t) = 1$. 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 Approach in Theory

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 include the impact of quality in a profit decomposition approach. 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 is included in a profit decomposition approach 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. Differences in output quality between firms may result in legitimate differences in required inputs to produce a given quantity of output. Moreover, variation in measured profitability, productivity and activity effects may result partially from these differences. 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.

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 $W = (W_1, W_2, ..., W_N)$. The positive vector of output quantities $Y = (Y_1, Y_2, ..., Y_M)$ where M denotes the total number of outputs is 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 $Y_l = \left(Y_{1,l}, Y_{2,l}, ..., Y_{M,L}\right)$ 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 $P = \left(P_1, P_2, ..., P_M\right)$ is similarly separated into a positive vector of output prices for high quality $P_h = \left(P_{1,h}, P_{2,h}, ..., P_{M,H}\right)$ and a positive vector of output prices for low quality $P_l = \left(P_{1.l}, P_{2,l}, ..., P_{M,L}\right)$ 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 $P_l$ and using Bennet indicators, $\overline{P}_h = 1/2\left(P_h^{t+1} + P_h^t\right)$, $\overline{P}_l = 1/2\left(P_l^{t+1} + P_l^t\right)$, $\overline{W} = 1/2\left(W^{t+1} + W^t\right)$, $\overline{X} = 1/2\left(X^{t+1} + X^t\right)$, $\overline{Y}_h = 1/2\left(Y_h^{t+1} + Y_h^t\right)$, $\overline{Y}_l = 1/2\left(Y_l^{t+1} + Y_l^t\right)$ profit change between period t and t+1, $\Pi^{t+1} - \Pi^t$, is decomposed as follows:

$$\begin{aligned}\Pi^{t+1} - \Pi^t = {} & [\overline{P}_h\left(Y_h^{t+1} - Y_h^t\right) + \overline{P}_l\left(Y_l^{t+1} - Y_l^t\right)] - \overline{W}\left(X^{t+1} - X^t\right) \quad \textit{quantity effect} \\ & + [\overline{Y}_h\left(P_h^{t+1} - P_h^t\right) + \overline{Y}_l\left(P_l^{t+1} - P_l^t\right)] - \overline{X}\left(W^{t+1} - W^t\right) \quad \textit{price effect}\end{aligned} \tag{8}$$

The quantity effect captures the contribution to profit changes from a change in output production of *high and low quality* and input usage, while the price effect shows the contribution to profit changes from a change in output prices for high and low quality and input prices. The quantity effect shows that profits may increase due to a rise in output production of high and low quality in excess of the corresponding input rise while the price effect shows that profits may also raise due to an increase in output prices for high and low quality 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.

Given that $Y = Y_h + Y_l$, and the output prices $P_h$, $P_l$ in the second stage the quantity effect can be decomposed into a *productivity* and an *activity* effect as follows:

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

$$=\left[\overline{W}\left(X^{t}-X^{B}\right)-\overline{W}\left(X^{t+1}-X^{C}\right)\right] \quad productivity\ effect \tag{9}$$

$$+\left[[\overline{P}_h\left(Y_h^{t+1}-Y_h^{t}\right)+\overline{P}_l\left(Y_l^{t+1}-Y_l^{t}\right)]-\overline{W}\left(X^{C}-X^{B}\right)\right] \quad activity\ effect$$

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 for high and low quality, $Y^t=Y_h^t+Y_l^t$ 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 $[\left(Y_h^{t+1}-Y_h^{t}\right)+\left(Y_l^{t+1}-Y_l^{t}\right)]$ is positive it reflects a rise in output of high and low quality 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.

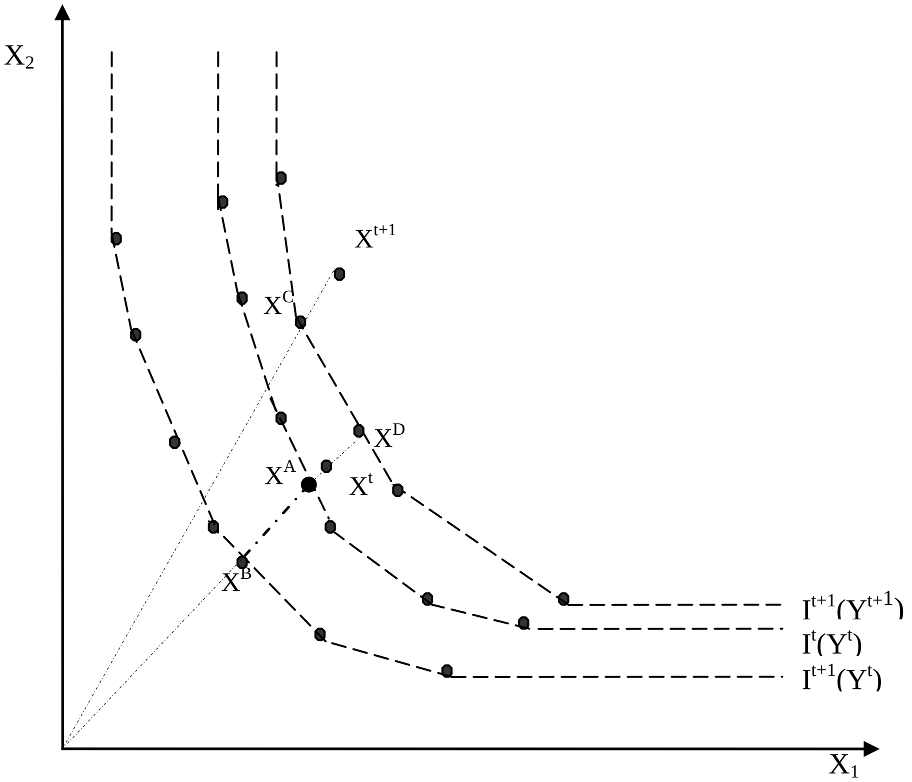


**Figure 1- Productivity Effect**

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

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

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

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.

Given that $Y = Y_h + Y_l$, and the output prices $P_h$ and $P_l$, the activity effect can be further decomposed as follows:

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

$$= \overline{W}\left(X^D - X^C\right) \qquad \textit{resourcemix effect} \qquad (11)$$

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

$$+\overline{W}\left(X^B - X^D\right) - [\overline{P}_h\left(Y_h^t - Y_h^{\,E}\right) + \overline{P}_l\left(Y_l^t - Y_l^{\,E}\right)] \quad \textit{scale effect}$$

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 of high and low quality 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 of high and low quality from $Y^E$ to $Y^{t+1}$, where $Y^{t+1} = Y_h^{t+1} + Y_l^{t+1}$. Note that $Y^E$ reflects the output mix of high and low quality 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 high and low quality 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 of high and low quality 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 of high and low quality 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 of high and low quality on t+1 technology using respectively input levels $X^B$ and $X^D$ already defined in Figure 1.

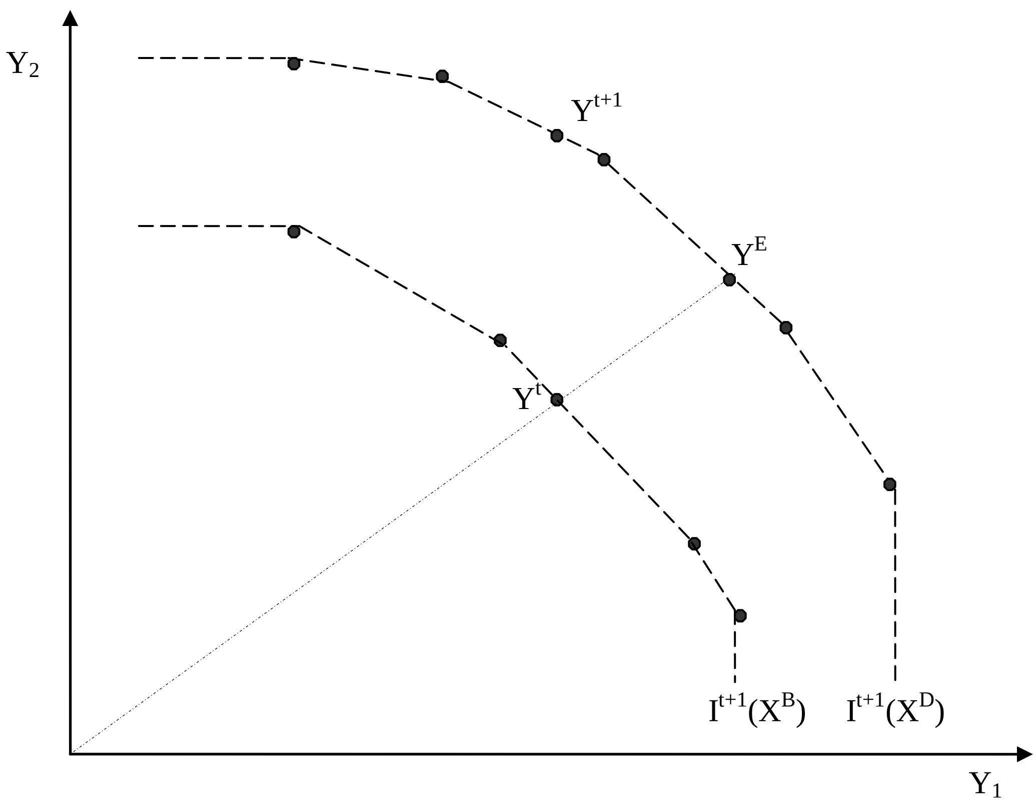


**Figure 2- Activity Effect**

## 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. Therefore, given the assumption that $Y = Y_h + Y_l$ the recovery of the unobserved quantities from the linear programming models (13)-(17) requires the inclusion of two output vectors, $Y_h$ and $Y_l$ .

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

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 $\phi$ denote a scalar, which represents the proportional contraction of the input vector, given the output vector and $\theta$ 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 $t = 1,2,\ldots,T$ . 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:

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

The variables $\lambda^k = \left(\lambda_1^k, \lambda_2^k, \ldots, \lambda_J^k\right)$ k=1…t whose optimal values are to be determined by the above model lead to the estimate the proportional reduction $\phi^A$ 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. Note that $\phi^A$ is the optimal value of $\phi$ as derived from model (13) after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

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

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

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. Note that $\phi^B$ is the optimal value of $\phi$ as derived from model (14) after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

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

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

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. Note that $\phi^C$ is the optimal value of $\phi$ as derived from model (15) after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

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

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

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. Note that $\phi^D$ is the optimal value of $\phi$ as derived from model (16) after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

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

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

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. Note that $\theta^E$ is the optimal value of $\theta$ as derived from model (17) after substituting the two sets of output constraints (high and low quality) for the aggregate output set.

## 2.4. Profit Decomposition Approach in Practice

The above modifications in the profit decomposition with adjustments for quality, equations (8)-(11) can be readily implemented if data for multiple output quality levels is available. However, in the UK water and sewerage 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.

As the technology set includes the set of all feasible inputs and outputs adjusted for high and low quality, the input and output set, input and output isoquant and input and output distance functions are by definition equivalent to those employed in (8) to (11). However, given the single output price, $P = P_h = P_l$, profits decompose into a quantity and price effect as follows, using Bennet indicators, $\overline{P} = 1/2\left(P^{t+1} + P^t\right)$, $\overline{W} = 1/2\left(W^{t+1} + W^t\right)$, $\overline{X} = 1/2\left(X^{t+1} + X^t\right)$, $\overline{Y}_h = 1/2\left(Y_h^{t+1} + Y_h^t\right)$, $\overline{Y}_l = 1/2\left(Y_l^{t+1} + Y_l^t\right)$:

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

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:

$$
\begin{aligned}
&\overline{P}[(Y_h^{t+1} - Y_h^{t}) + (Y_l^{t+1} - Y_l^{t})] - \overline{W}(X^{t+1} - X^{t}) \quad \textit{quantity effect} \\
&= [\overline{W}(X^{t} - X^{B'}) - \overline{W}(X^{t+1} - X^{C'})] \quad \textit{productivity effect} \qquad (9') \\
&+ [\overline{P}[(Y_h^{t+1} - Y_h^{t}) + (Y_l^{t+1} - Y_l^{t})] - \overline{W}(X^{C'} - X^{B'})] \quad \textit{activity effect}
\end{aligned}
$$

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.

Consideration of (10) reveals that the equivalence of the productivity effect, regardless of whether we assume quality differentiated or undifferentiated output prices, extends to its decomposition into technical change and efficiency change. Given the assumption of quality differentiated output quantities but quality undifferentiated output prices, the decomposition of the activity effect into resource mix, product mix and scale effect in equation (11) will become:

$$\begin{aligned}
&\overline{P}[(Y_h^{t+1}-Y_h^t)+(Y_l^{t+1}-Y_l^t)]-\overline{W}(X^{C'}-X^{B'}) \quad \textit{activity effect}\\
&=\overline{W}(X^{D'}-X^{C'}) \quad \textit{resource mix effect} \qquad (11')\\
&-\overline{P}[(Y_h^{E'}-Y_h^{t+1})+(Y_l^{E'}-Y_l^{t+1})] \quad \textit{product mix effect}\\
&+\overline{W}(X^{B'}-X^{D'})-\overline{P}[(Y_h^t-Y_h^{E'})+(Y_l^t-Y_l^{E'})] \quad \textit{scale effect}
\end{aligned}$$

The difference between equations (11') and (11) is on the weights employed to evaluate changes in the product mix effect and the output scale effect since they are now calculated using the observed output prices, $P$, instead of $P_h$, $P_l$. 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. Nevertheless, we particularly emphasize that the resource mix effect and the input scale effect will be exactly the same as in equation (11) because they 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. As before, 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 $Y_l$. Therefore, the results for the resource mix, product mix and scale effect in equation (11') will not be different from those yielded by equation (11).

This section provided a profit decomposition framework which makes allowances for differences in the quality of output. The differentiation of output quantities by quality does allow an alternative decomposition of the aggregate quantity effect. 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, the input side of the quantity effect, the input side of the activity effect and the input side of the scale effect are invariant to the assumption of quality undifferentiated output prices, in a model that allows for quality differentiated output quantities. In contrast, the output side of the quantity effect, the output side of the activity effect, the output side of the scale effect, the output price effect and the product mix effect will vary if quality differentiated output prices are available, in a model that allows for quality differentiated output quantities.

Finally, in the linear programming models (13)-(17) we further impose 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.

## 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.[1] 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,

[1] While it would be particularly desirable to disaggregate other input usage data further and in particular to allow for separate energy and chemical usage inputs, the data available at company level from Ofwat's regulatory return does not allow a further meaningful decomposition of other input usage.

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 measure 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 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).

[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.

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

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 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 in equation 10, technical regress is not allowed, $X^A - X^B$ measures only technical progress (see Figure 3). 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.

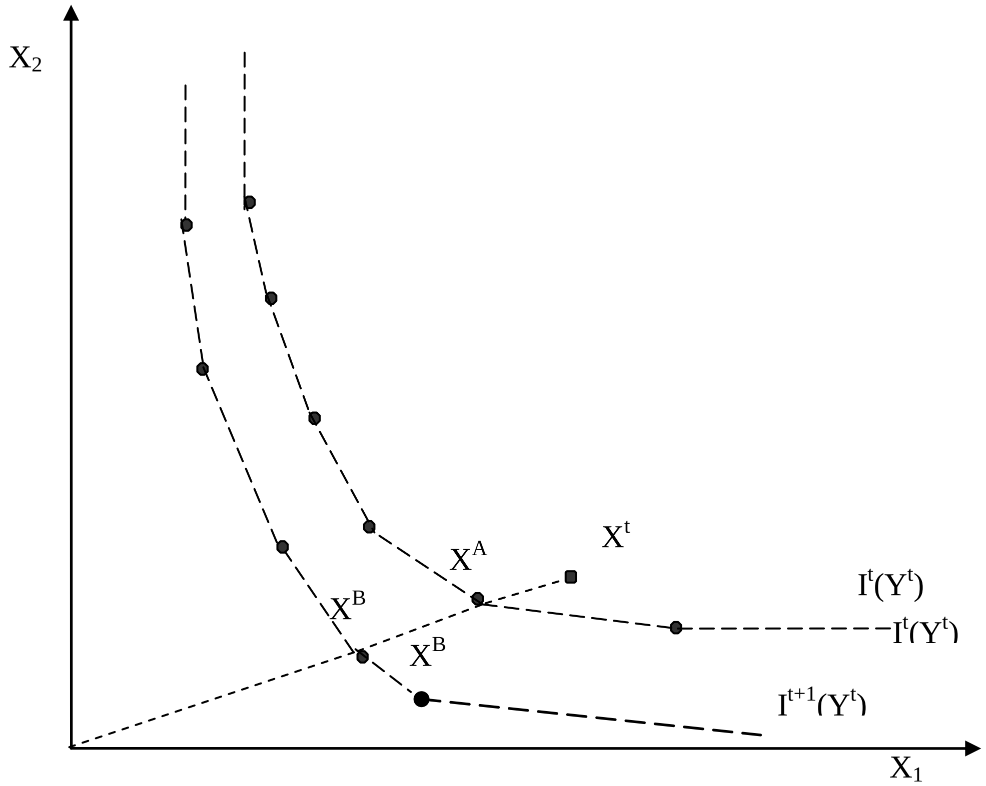


**Figure 3- Technical Progress**

## 4. Empirical Results

In this section we use the methodology outlined above to decompose the profit changes of the water and sewerage sector in England and Wales during the period 1994-2008. 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**

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. Over the entire 1994-2008 period, the quantity effect, efficiency change, technical change, resource mix and product mix effect contributed positively to profit changes, while the price and scale 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 |
| 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 2- Cumulative High And Low Quality Adjusted 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.

Table 2 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.

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. In aggregate, the productivity effect increased profits substantially by 563.5 and 457.4 million pounds respectively during the years 1994-2000 and 2000-2005, whereas its magnitude reduced during the years 2005-2008 since it slightly increased profits by 68.6 million pounds during the years 2005-2008. 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, it is concluded that in aggregate the 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. 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 did not lower costs and reduced profits significantly during the years 2000-2005 and 2005-2008 by 383.5 and 337.3 million pounds. The substantial savings occurred by the resource mix effect were lost due to excessive mergers, the negative scale effect implying that during the entire period, the water and sewerage industry was operating under diseconomies of scale which affected negatively aggregate economic profitability. Changes in the mix of outputs, the production of more output for water services than sewerage services 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. 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%.

The results indicate that during the years 1994-2000 when price caps were tightened after the 1994 price review, profits increased. This was attributed to the positive cumulative quantity effect, which offset the overall negative price effect. There were significant increases in the production of high quality output and reductions in the production of low quality output which outstripped the overall negative price effect, inputs prices increased greater than output prices.

There were also significant improvements in productivity mainly attributable to technical change, indicating that the most productive companies significantly improved their performance, whereas gains in efficiency were positive but small. Furthermore, there was evidence that changes in the mix of inputs had a positive impact on aggregate profitability until 2000, whereas scale effect and output mix effect contributed negatively to profit changes. 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. Moreover, adjusting to a more cost efficient input mix and a shift to the production of more output for water services than sewerage services also appeared to have lowered costs and increased profits. However, the negative impact of scale effect on aggregate profitability became greater implying that mergers occurred in 2000/01 eventually reduced 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 outstripped by large increases in input prices. Changes in the mix of inputs, outputs and technical change had a positive impact on aggregate profitability. However, the negative efficiency change and scale effect, no gains in productivity by less productive firms and increases in the scale of operations (diseconomies of scale) significantly reduced aggregate profitability.

Over the whole period, the major positive determinants on the quantity effect and eventually on profit change as defined in equations (8') to (11') came from the technical change and the resource mix effect, whereas the impact of the efficiency change and product mix effect on profit changes was small. The results suggest that although technical change contributed positively on profit changes over the entire period, it started to fall after 2000 implying that the frontier companies achieved significant productivity improvements before 2000. The efficiency change effect became negative during the years 2005-2008 indicating that gains in productivity by less productive firms occurred during the years 1994-2005. As far as the resource mix effect is concerned, its magnitude significantly increased after 2000, indicating that the water and sewerage industry moved to a more cost efficient allocation of resources more by substituting labour with capital. Finally, the product mix effect was negative during the years 1994-2000 but slightly increased after 2000 indicating that the water and sewerage industry moved to the production of more output for water than sewerage services contributing positively to profit changes.

Moreover, the major negative determinants on the quantity effect and eventually on profit changes came from the scale effect whose magnitude substantially increased during the years 2000-2008. This finding suggests that the mergers occurred in 2000/01 had a negative impact on aggregate profitability. As a result, on average the water and sewerage companies operated under diseconomies of scale which contributed negatively to profits. This finding is apparent during the years 2000-2005 when the profits substantially fell due to the negative impact from the mergers combined with the high increase in input prices. Also, during the years 2005-2008, the bigger negative scale effect offset the positive impact of technical change and resource mix effect resulting in a small decrease in aggregate profitability. Any substantial savings occurred by the resource mix effect were lost due to excessive mergers, indicating that over the whole period the water and sewerage companies were operating under diseconomies of scale which had a negative impact on aggregate profitability.

## 5.Conclusions

In this study, we followed the input oriented profit decomposition approach of De Witte & Saal (2010) and by making allowances for differences in the quality of output, we decompose the output effect into high quality and low quality output effect. We decomposed profit changes into various factors that are of great significance for the regulator and the regulated firms such as quantity and price effect, high and low quality output effect, technical change, efficiency change, resource mix, product mix and scale effect. 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 results indicated 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. The positive output effect was attributed to a substantial increase in high quality outputs which outstripped the negative low quality output effect, which was the result of low quality output reductions during the years 1994-2005.

The major determinants on the quantity effect and eventually, on profit change came from the technical change whose magnitude, however, substantially reduced during the years 2005-2008, the resource mix effect, a shift to a more cost efficient allocation of resources by substituting labour with capital, and the negative scale effect whose magnitude substantially increased after 2000, suggesting that the mergers occurred in 2000/01 did not eventually lower costs. Efficiency change and product mix effect were found to have a small but positive impact on profit changes. Any substantial savings occurred by the resource mix effect were lost due to excessive mergers, indicating that over the whole period the water and sewerage companies were operating under diseconomies of scale which had a negative impact on aggregate profitability.

Our methodology facilitated 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 enables regulators and regulated companies to identify the sources of profit variation such as price effects, productivity effects, changes in the mix of resources, outputs and the scale of operations and aid them to evaluate firstly the effectiveness of the price cap scheme and the performance of the regulated companies. Secondly and more significantly, 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. Moreover, 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.

Finally, the results from our profit decomposition approach have significant policy implications for the regulated water and sewerage industry in England and Wales and can be summarised 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 change 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 (forward-looking).

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