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The purpose of this paper is the evaluation of various profit drivers such as price changes, productivity changes and quality levels on the financial performance of the Water and Sewerage Companies (WaSCs) over time in the case when the number of observations is limited. We thereby follow Maziotis, Saal and Thanassoulis (2012) approach and extend it by measuring the impact of exogenous factors such as drinking water and sewerage treatment quality on profitability, productivity and price performance measures. The results suggest that while quality improvements have significantly contributed to the productivity performance of the WaSCs, they have also contributed negatively to their price performance. Overall, after 2000 steady reductions in average price performance, gains in productivity and stable economic profitability were apparent. This trend indicates Ofwat's policy on passing productivity benefits to consumers, and sustaining stable profitability than it was in earlier regulatory periods. This technique is of great interest for 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, when the sample size is extremely limited.

Keywords: Profit Decomposition, Productivity, Price Performance, Quality Change, Panel Index Numbers, Regulation, Water and Sewerage Industry

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PROFIT, PRODUCTIVITY, PRICE AND QUALITY PERFORMANCE CHANGES IN THE ENGLISH AND WELSH WATER AND SEWERAGE COMPANIES

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Abstract

The purpose of this paper is the evaluation of various profit drivers such as price changes, productivity changes and quality levels on the financial performance of the Water and Sewerage Companies (WaSCs) over time in the case when the number of observations is limited. We thereby follow Maziotis, Saal and Thanassoulis (2012) approach and extend it by measuring the impact of exogenous factors such as drinking water and sewerage treatment quality on profitability, productivity and price performance measures. The results suggest that while quality improvements have significantly contributed to the productivity performance of the WaSCs, they have also contributed negatively to their price performance. Overall, after 2000 steady reduction in average price performance, gains in productivity and stable economic profitability were apparent. This trend indicates Ofwat's policy on passing productivity benefits to consumers, and sustaining stable profitability than it was in earlier regulatory periods. This technique is of great interest for 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, when the sample size is extremely limited.

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1. Introduction[1]

The water and sewerage industry in England and Wales was privatized in 1989 and before privatization there were 10 Regional Water Authorities responsible for the water and sewerage supply in England and Wales and 29 Statutory Water companies, which were already privatized companies that were only responsible for the supply of water. After 1989, the 10 Regional Water Authorities were privatized and formed the Water and Sewerage Companies (WaSCs) and the 29 Statutory Water Companies became Water Only Companies (WoCs). Today there are 10 WaSCs whose duties include the supply of water in areas that are not supplied by the WoCs, and the collection, treatment and disposal of sewerage in all areas. However, there are now only 11 WoCs, after mergers and takeovers. The WaSCs supply drinking water to 80% of the population in England and Wales with WoCs supplying the rest. There are three regulatory bodies in the water and sewerage industry. The Office of Water Services (Ofwat), which is the economic regulator and sets the price limits for each company every five years, the Environment Agency (EA), which is responsible for pollution control, licensing and regulation of water abstraction, and the Drinking Water Inspectorate (DWI), which is responsible for controlling and monitoring drinking water quality.

There were plenty of studies in the past that used Stochastic Frontier Analysis (SFA) or Data Envelopment Analysis (DEA) techniques to measure the productivity performance of the UK water and sewerage industry before and after privatization and evaluate the impact of the regulatory price cap scheme on their financial performance (see Maziotis (2012) for a comprehensive literature review). However, few studies exist that use index number techniques to measure the overall performance (profits, productivity and price performance) of the UK water and sewerage sector. The importance of index numbers lies on the fact that they allow the measurement of the performance of companies when the number of observations is extremely limited. A significant advantage compared to other estimation techniques such as SFA and DEA which require a relatively large number of observations to specify an efficient frontier

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

The first profit decomposition analysis using index numbers to assess performance measurement in the UK water and sewerage industry was developed by Saal and Parker (2001), originally introduced by Waters & Tretheway (1999) for the Australian telecommunication industry. Saal and Parker (2001) employed a temporal (over time) Tornqvist index approach to measure the impact of privatization and regulation on productivity (TFP), price performance (TPP) and profitability for WaSCs for the years 1985-2000. The authors concluded that indicated that privatization did not lead to a significant improvement in the overall productivity growth of WaSCs, whereas the tightened 1994/95 price review reduced firm-specific economic profitability but there were not any significant improvements in productivity. Moreover, Saal and Parker's (2001) approach was then developed by Maziotis, Saal and Thanassoulis (2009) and (2012). The former used a cross sectional (spatial) index number technique to allow for the cross-sectional (spatial) measurement of TFP, regulatory price performance (TPP), and profitability and showed the subsequent comparison of how these cross sectional measures have changed over time. Changes in TFP, TPP and profitability were measured after taking into account the impact of exogenous characteristics such as drinking water and sewerage treatment quality. Maziotis, Saal and Thanassoulis (2012) developed a panel index approach across WaSCs over time to decompose unit-specific (temporal) index number based profitability growth as a function of the profitability, productivity and price performance growth achieved by benchmark firms, and the catch-up to the benchmark firm achieved by less productive firms. However, the authors did not take into account the impact of quality in the productivity and price performance measures.

Therefore, the purpose of this paper is to follow Maziotis, Saal and Thanassoulis (2012) approach and extend it by measuring the impact of exogenous factors on profitability, productivity and price performance measures. As adjustments for quality affect the productivity and price performance measures leaving the measured economic profitability unchanged, the unit-specific profitability growth can be expressed as a function of the unit-specific quality adjusted productivity and quality-adjusted price performance change. This can be further decomposed as a function of the quality adjusted catch-up in productivity, and the quality adjusted productivity growth of the benchmark firm, and the quality adjusted catch-up in price performance, and the quality adjusted price performance growth of the benchmark firm. The inclusion of quality in our analysis allows us to finally decompose unit-specific economic profitability change as a function of the quality unadjusted catch-up in productivity, the catch-up in quality regarding productivity, and the quality-unadjusted productivity and quality performance over time of the benchmark firm, and the quality unadjusted catch-up in price performance, the catch-up in quality regarding price performance, and the price performance and quality growth of the benchmark firm. We illustrate our analytical decomposition of profit change with an empirical application to the regulated English and Welsh water and sewerage industry during the period 1991-2008.

This paper unfolds as follows. Sections 2 and 3, consider the methodology necessary to apply this approach in a bilateral and multilateral context. The following section provides a discussion of data employed and the next section details the empirical results. Section 6 eventually concludes.

2. Methodology

2.1. Unit specific Profitability, Productivity and Price Performance Indices

Following the approach of Waters & Tretheway (1999), Saal & Parker (2001) and Maziotis, Saal and Thanassoulis (2012) we first measure profits, productivity and price performance between two time periods, year t and the base year 1 for firm i. Economic profits of firm i at the base year 1, $\Pi_{i,1}$, are defined as a ratio of total revenues, $R_{i,1}$ and total costs in year 1, $C_{i,1}$. Total revenues of a firm i at period 1, $R_{i,1}$, are defined as $R_{i,1} = P_{i,1} \times Y_{i,1}$, where $P_{i,1}$ and $Y_{i,1}$ respectively represent the output price index and the aggregate output index at period 1. Similarly, $C_{i,1} = W_{i,1} \times X_{i,1}$ .We can thus define and decompose a unit-specific (temporal) index of economic profitability for firm i at period t relative to the base period 1, $\pi_{i,t}^{US}$, as follows:

$$\pi_{i,t}^{US} = \frac{\Pi_{i,t}}{\Pi_{i,1}} = \frac{\dfrac{R_{i,t}}{C_{i,t}}}{\dfrac{R_{i,1}}{C_{i,1}}} = \frac{\dfrac{P_{i,t}Y_{i,t}}{W_{i,t}X_{i,t}}}{\dfrac{P_{i,1}Y_{i,1}}{W_{i,1}X_{i,1}}} = \frac{TFP_{i,t}}{TFP_{i,1}} \times \frac{TPP_{i,t}}{TPP_{i,1}} = \frac{\dfrac{Y_{i,t}}{Y_{i,1}}}{\dfrac{X_{i,t}}{X_{i,1}}} \times \frac{\dfrac{P_{i,t}}{P_{i,1}}}{\dfrac{W_{i,t}}{W_{i,1}}} = \frac{Y_{i,t}^{US}}{X_{i,t}^{US}} \times \frac{P_{i,t}^{US}}{W_{i,t}^{US}} = TFP_{i,t}^{US} \times TPP_{i,t}^{US} \quad (1)$$

Thus, the unit-specific economic profitability index, $\pi_{i,t}^{US}$ can be expressed as a function of an index of unit-specific total factor productivity in period t relative to the base year 1, $TFP_{i,t}^{US}$ and an index of unit-specific total price performance between period t and 1, $TPP_{i,t}^{US}$. As $TFP_{i,t}^{US} = Y_{i,t}^{US} / X_{i,t}^{US}$ and $TPP_{i,t}^{US} = P_{i,t}^{US} / W_{i,t}^{US}$ these indices can be further decomposed as functions of the unit-specific output ($Y_{i,t}^{US} = Y_{i,t} / Y_{i,1}$), input ($X_{i,t}^{US} = X_{i,t} / X_{i,1}$), output price ($P_{i,t}^{US} = P_{i,t} / P_{i,1}$) and input price ($W_{i,t}^{US} = W_{i,t} / W_{i,1}$) indices. This decomposition highlights that observed changes in unit-specific profitability over time can be explained by changes in productivity, changes in price performance, or changes in both.

2.2. Spatial Profitability, Productivity, and Price Performance Indices

We next consider the relationship between profits, productivity and price performance for firm i relative to a base firm b at time t, which we call a spatial index, thereby adopting the terminology employed in the price index literature (Hill, 2004). As a result of its definition, these indices only directly measure differences in performance in the spatial dimension (between firms) at any given time. Economic profits of the base firm b at time t, $\Pi_{b,t}$, are defined as a ratio of its total revenues, $R_{b,t}$ and total costs, $C_{b,t}$, at time t. Thus, the total revenues of the base firm b at period t are defined as $R_{b,t} = P_{b,t} \times Y_{b,t}$, where $P_{b,t}$ and $Y_{b,t}$ present the output price index and the aggregate output index respectively of the base firm b at period t. Its total costs at year t, $C_{b,t}$, are defined as $C_{b,t} = W_{b,t} \times X_{b,t}$, where $W_{b,t}$ and $X_{b,t}$ denotes the input price index and the aggregate input index respectively of the base firm at year t. Similarly, we can define economic profits of any firm i at period t, $\Pi_{i,t}$ as a ratio of its total revenues, $R_{i,t}$ and its total costs, $C_{i,t}$. We can thus define and decompose a spatial economic profitability index for any firm i relative to the base firm b at period t, $\pi_{b,t}^{S}$ as follows:

$$\pi_{i,t}^{S} = \frac{\Pi_{i,t}}{\Pi_{b,t}} = \frac{\frac{R_{i,t}}{C_{i,t}}}{\frac{R_{b,t}}{C_{b,t}}} = \frac{\frac{P_{i,t}Y_{i,t}}{W_{i,t}X_{i,t}}}{\frac{P_{b,t}Y_{b,t}}{W_{b,t}X_{b,t}}} = \frac{TFP_{i,t}}{TFP_{b,t}} \times \frac{TPP_{i,t}}{TPP_{b,t}} = \frac{\frac{Y_{i,t}}{Y_{b,t}}}{\frac{X_{i,t}}{X_{b,t}}} \times \frac{\frac{P_{i,t}}{P_{b,t}}}{\frac{W_{i,t}}{W_{b,t}}} = \frac{Y_{i,t}^{S}}{X_{i,t}^{S}} \times \frac{P_{i,t}^{S}}{W_{i,t}^{S}} = TFP_{i,t}^{S} \times TPP_{i,t}^{S} \quad (2)$$

Thus, at time t, a spatial economic profitability index, $\pi_{i,t}^{S}$ can be expressed as a function of an index of spatial total factor productivity for firm i relative to the base firm *b*, $TFP_{i,t}^{S}$ and a spatial index of total price performance between firm i and the base firm *b*, $TPP_{i,t}^{S}$. As $TFP_{i,t}^{S} = Y_{i,t}^{S} \big/ X_{i,t}^{S}$ and $TPP_{i,t}^{S} = P_{i,t}^{S} \big/ W_{i,t}^{S}$ these indices can be further decomposed as functions of the spatial output ($Y_{i,t}^{S} = Y_{i,t} \big/ Y_{b,t}$), input ($X_{i,t}^{S} = X_{i,t} \big/ X_{b,t}$), output price ($P_{i,t}^{S} = P_{i,t} \big/ P_{b,t}$) and input price ($W_{i,t}^{S} = W_{i,t} \big/ W_{b,t}$) indices. This decomposition of spatial profitability highlights that, at any given time, observed differences in profitability between firms can be explained by differences in productivity, differences in price performance, or differences in both.

By definition spatial indices estimate firm *i*'s performance relative to any potential base firm *b*, and can therefore be employed to measure catch up in relative performance. Thus, if we have access to data for the base year 1 and any other year t, we can define and decompose an index of economic profitability catch up for any firm i at time t and relative to the base firm b at period t, $\pi_{i,t}^{C}$,as follows:

$$\pi_{i,t}^{C} = \frac{\pi_{i,t}^{S}}{\pi_{i,1}^{S}} = \frac{TFP_{i,t}^{S}}{TFP_{i,1}^{S}} \times \frac{TPP_{i,t}^{S}}{TFP_{i,1}^{S}} = \frac{\dfrac{Y_{i,t}^{S}}{Y_{i,1}^{S}}}{\dfrac{X_{i,t}^{S}}{X_{i,1}^{S}}} \times \frac{\dfrac{P_{i,t}^{S}}{P_{i,1}^{S}}}{\dfrac{W_{i,t}^{S}}{W_{i,1}^{S}}} = \frac{Y_{i,t}^{C}}{X_{i,t}^{C}} \times \frac{P_{i,t}^{C}}{W_{i,t}^{C}} = TFP_{i,t}^{C} \times TPP_{i,t}^{C} \tag{3}$$

Thus, for firm i at time t, an index of economic profitability catch up, $\pi_{i,t}^{C}$ can be expressed as a function of an index of total factor productivity catch up for firm i relative to the base firm *b*, $TFP_{i,t}^{C}$ and an index of total price performance catch up relative to firm *b*, $TPP_{i,t}^{C}$. As $TFP_{i,t}^{C} = Y_{i,t}^{C} \big/ X_{i,t}^{C}$ and $TPP_{i,t}^{C} = P_{i,t}^{C} \big/ W_{i,t}^{C}$ these indices can be further decomposed as functions of catch up indices for outputs ($Y_{i,t}^{C} = Y_{i,t}^{S} \big/ Y_{i,1}^{S}$), inputs ($X_{i,t}^{C} = X_{i,t}^{S} \big/ X_{i,1}^{S}$), output prices ($P_{i,t}^{C} = P_{i,t}^{S} \big/ P_{i,1}^{S}$) and input prices ($W_{i,t}^{C} = W_{i,t}^{S} \big/ W_{i,1}^{S}$). This decomposition of profitability catch up highlights that a firm's catch up in profitability can be explained not only by improving its productivity performance relative to the base firm, but also by improving its price performance relative to the base firm.

2.3. Relative Profitability, Productivity and Price Performance Indices

We finally define the relationship between profits, productivity and price performance for any firm i at any time t relative to a base firm b at the base time1. As by construction these indices are measured relative to a constant base for all t and all i, they therefore capture differences in both the spatial and the temporal dimensions for any given firm at any given time.

As above, we define the economic profits of the base firm b at year 1, $\Pi_{b,1}$, as a ratio of its total revenues, $R_{b,1}$ and total costs, $C_{b,1}$, at year 1. Thus, the total revenues of the base firm b at period 1 are defined as $R_{b,1} = P_{b,1} \times Y_{b,1}$, where $P_{b,1}$ and $Y_{b,1}$ present the output price index and the aggregate output index respectively at period 1. Its total costs at year 1, $C_{b,1}$, are defined as $C_{b,1} = W_{b,1} \times X_{b,1}$, where $W_{b,1}$ and $X_{b,1}$ denotes the input price index and the aggregate input index respectively of the base firm at year 1. We can thus define and decompose a relative index of economic profitability change at time t for firm i relative to the base firm b at time 1, $\pi_{i,t}^{R}$, as follows:

$$\pi_{i,t}^{R} = \frac{\Pi_{i,t}}{\Pi_{b,1}} = \frac{\frac{R_{i,t}}{C_{i,t}}}{\frac{R_{b,1}}{C_{b,1}}} = \frac{\frac{P_{i,t}Y_{i,t}}{W_{i,t}X_{i,t}}}{\frac{P_{b,1}Y_{b,1}}{W_{b,1}X_{b,1}}} = \frac{TFP_{i,t}}{TFP_{b,1}} \times \frac{TPP_{i,t}}{TPP_{b,1}} = \frac{\frac{Y_{i,t}}{Y_{b,1}}}{\frac{X_{i,t}}{X_{b,1}}} \times \frac{\frac{P_{i,t}}{P_{b,1}}}{\frac{W_{i,t}}{W_{b,1}}} = \frac{Y_{i,t}^{R}}{X_{i,t}^{R}} \times \frac{P_{i,t}^{R}}{W_{i,t}^{R}} = TFP_{i,t}^{R} \times TPP_{i,t}^{R} \quad (4)$$

Thus, for firm i at time t, the relative economic profitability index, $\pi_{i,t}^{R}$ can be expressed as a function of an index of relative total factor productivity for firm i at time t relative to the base firm b at time 1, $TFP_{i,t}^{R}$,and an index of total price performance for firm i at time t relative to the base firm b at time 1,, $TPP_{i,t}^{R}$. As $TFP_{i,t}^{R} = Y_{i,t}^{R} / X_{i,t}^{R}$ and $TPP_{i,t}^{R} = P_{i,t}^{R} / W_{i,t}^{R}$ these indices can be further decomposed as functions of the relative output ($Y_{i,t}^{R} = Y_{i,t} / Y_{b,1}$), input ($X_{i,t}^{R} = X_{i,t} / X_{b,1}$), output price ($P_{i,t}^{R} = P_{i,t} / P_{b,1}$) and input price ($W_{i,t}^{R} = W_{i,t} / W_{b,1}$) indices.

Given the binary definition of $\pi_{i,t}^{P}$ and its components ($TFP_{i,t}^{R}$, $TPP_{i,t}^{R}$, $Y_{i,t}^{R}$, $X_{i,t}^{R}$, $P_{i,t}^{R}$ and $W_{i,t}^{R}$) these relative performance estimates are theoretically equivalent to the separate binary performance estimates provided by the unit-specific and spatial performance measures. Thus, as $\pi_{i,t}^{US} = \pi_{i,t}^{R} / \pi_{i,1}^{R}$, $TFP_{i,t}^{US} = TFP_{i,t}^{R} / TFP_{i,1}^{R}$, $TPP_{i,t}^{US} = TPP_{i,t}^{R} / TPP_{i,1}^{R}$, $Y_{i,t}^{US} = Y_{i,t}^{R} / Y_{i,1}^{R}$, $X_{i,t}^{US} = X_{i,t}^{R} / X_{i,1}^{R}$, $P_{i,t}^{US} = P_{i,t}^{R} / P_{i,1}^{R}$ and $W_{i,t}^{US} = W_{i,t}^{R} / W_{i,1}^{R}$ it is straightforward to demonstrate that $\pi_{i,t}^{US}$ can be estimated and fully decomposed as a function of relative performance measure estimates.

$$\pi_{i,t}^{US} = \frac{\pi_{i,t}^{R}}{\pi_{i,1}^{R}} = \frac{\dfrac{Y_{i,t}^{R}}{Y_{i,1}^{R}}}{\dfrac{X_{i,t}^{R}}{X_{i,1}^{R}}} \times \frac{\dfrac{P_{i,t}^{R}}{P_{i,1}^{R}}}{\dfrac{W_{i,t}^{R}}{W_{i,1}^{R}}} = \frac{TFP_{i,t}^{R}}{TFP_{i,1}^{R}} \times \frac{TPP_{i,t}^{R}}{TPP_{i,1}^{R}} \tag{5}$$

Similarly, as $\pi_{i,t}^{S} = \pi_{i,t}^{R} / \pi_{b,t}^{R}$, $TFP_{i,t}^{S} = TFP_{i,t}^{R} / TFP_{b,t}^{R}$, $TPP_{i,t}^{S} = TPP_{i,t}^{R} / TPP_{b,t}^{R}$, $Y_{i,t}^{S} = Y_{i,t}^{R} / Y_{b,t}^{R}$, $X_{i,t}^{S} = X_{i,t}^{R} / X_{b,t}^{R}$, $P_{i,t}^{S} = P_{i,t}^{R} / P_{b,t}^{R}$ and $W_{i,t}^{S} = W_{i,t}^{R} / W_{b,t}^{R}$:

$$\pi_{i,t}^{S} = \frac{\pi_{i,t}^{R}}{\pi_{b,t}^{R}} = \frac{\dfrac{Y_{i,t}^{R}}{Y_{b,t}^{R}}}{\dfrac{X_{i,t}^{R}}{X_{b,t}^{R}}} \times \frac{\dfrac{P_{i,t}^{R}}{P_{b,t}^{R}}}{\dfrac{W_{i,t}^{R}}{W_{b,t}^{R}}} = \frac{TFP_{i,t}^{R}}{TFP_{b,t}^{R}} \times \frac{TPP_{i,t}^{R}}{TPP_{b,t}^{R}} \tag{6}$$

Estimates of $\pi_{i,t}^{C}$ can then be constructed with the underlying relative profitability indices, and can in fact be constructed as the ratio of either unit specific or spatial indices as defined in (5) and (6). This also clearly demonstrates that the catch up index is, at its core, simply a ratio of unit specific profitability growth rates.

$$\pi_{i,t}^{C} = \frac{\pi_{i,t}^{S}}{\pi_{i,1}^{S}} = \frac{\dfrac{\pi_{i,t}^{R}}{\pi_{b,t}^{R}}}{\dfrac{\pi_{i,1}^{R}}{\pi_{b,1}^{R}}} = \frac{\dfrac{\pi_{i,t}^{R}}{\pi_{i,1}^{R}}}{\dfrac{\pi_{b,t}^{R}}{\pi_{b,1}^{R}}} = \frac{\pi_{i,t}^{US}}{\pi_{b,t}^{US}} \tag{7}$$

Moreover, by rearranging (7) and decomposing the profitability index we can write:

$$\pi_{i,t}^{US} = \pi_{i,t}^{C} \times \pi_{b,t}^{US} = \left(TFP_{i,t}^{C} \times TFP_{b,t}^{US}\right) \times \left(TPP_{i,t}^{C} \times TPP_{b,t}^{US}\right) \tag{8}$$

Thus, given the availability of relative performance indices, the temporal economic profitability of a firm i over time, $\pi_{i,t}^{US}$ can be decomposed as a function of the profitability growth of the base firm b, $\pi_{b,t}^{US}$ and the profitability catch-up of the firm

i relative to the base firm between year 1 and t, $\pi_{i,t}^{C}$, e.g. profit performance of any firm can be decomposed into a measure capturing the profit change of a reference firm, and the given firm's performance change relative to that reference firm. Equation (8) therefore highlights the strong potential to apply this index based approach to regulatory settings where it is desirable to not only measure firm performance, but also to judge that performance relative to a base firm, normally defined as a "best practice" or "benchmark" firm. Equation (8) previously developed by Maziotis, Saal and Thanassoulis (2012) lacks the impact of exogenous factors like quality in a profit decomposition analysis.

Therefore, 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. Saal and Parker (2001) and Maziotis, Saal and Thanassoulis (2009) demonstrated that quality improvements do significantly impact temporal and spatial productivity and price performance estimates. Thus, we feel it is important to measure the impact of quality in our unit-specific, spatial and relative profitability, productivity and price performance measures, thereby allowing for the cross sectional and intertemporal variation in the sewage and drinking water quality. We therefore calculate quality-adjusted measures of output, as the product of output and a quality index following the approach of Saal and Parker (2000) and (2001), Stone & Webster Consultants (2004), Saal et al, (2007), Maziotis, Saal and Thanassoulis (2009). As a result, , quality is included in a profit decomposition approach as an exogenous factor and is intended to control for changes over the assesment period in water quality, environmental standards and characteristics that reflect differences between firms in terms of their operating environment (Stone & Webster Consultants, 2004).

Once the quality adjusted water and sewerage outputs are constructed, quality adjusted indices are straightforward to produce, by first producing spatially consistent quality adjusted output indices ($Y_{i,t}^{S,Q}$). A spatial aggregate quality-adjusted aggregated output price index is then constructed as $P_{i,t}^{S,Q} = R_{i,t}^{S} / Y_{i,t}^{S,Q}$. We can also derive a spatial implicit quality index ($Q^{S}_{i,t}$) which measures the implied difference in quality relative to the base firm as $Q^{S}_{i,t} = Y^{S,Q}_{i,t} \big/ Y^{S}_{i,t}$. Therefore, quality adjusted spatial outputs and output prices can also be respectively expressed as $Y^{S,Q}_{i,t} = Q^{S}_{i,t} Y^{S}_{i,t}$ and $P^{S,Q}_{i,t} = P^{S}_{i,t} \big/ Q^{S}_{i,t}$, which illustrate that the impact on spatial output quantities will be perfectly balanced by changes in spatial output prices. This also implies that measured spatial economic profitability ($\pi^{S}_{i,t}$) is not influenced by quality adjustment. In contrast, the impact of quality adjustment implies that quality adjusted spatial TFP can be expressed as $TFP^{S,Q}_{i,t} = Q^{S}_{i,t} TFP^{S}_{i,t}$ and similarly, quality adjusted spatial price performance can be expressed as $TPP^{S,Q}_{i,t} = TPP^{S}_{i,t} / Q^{S}_{i,t}$ and spatial economic profitability can be decomposed as, $\pi^{S}_{i,t} = TFP^{S,Q}_{i,t} TPP^{S,Q}_{i,t}$.

In an analogous manner, we can derive measures of relative quality adjusted output indices over time, $Y^{R,Q}_{i,t}$ and relative implicit quality index over time ($Q^{R}_{i,t}$) which measures the implied difference in quality over time relative to the base firm at the base period as $Q^{R}_{i,t} = Y^{R,Q}_{i,t} / Y^{R}_{i,t}$. Therefore, measures of quality adjusted relative outputs and output prices can also be expressed as $Y^{R,Q}_{i,t} = Q^{R}_{i,t} Y^{R}_{i,t}$ and $P^{R,Q}_{i,t} = P^{R}_{i,t} \big/ Q^{R}_{i,t}$. Thus, quality adjusted relative TFP and TPP over time can be expressed as $TFP^{R,Q}_{i,t} = Q^{R}_{i,t} TFP^{R}_{i,t}$ and $TPP^{R,Q}_{i,t} = TPP^{R}_{i,t} / Q^{R}_{i,t}$, whereas the relative economic profitability over time as $\pi^{R}_{i,t} = TFP^{R,Q}_{i,t} TPP^{R,Q}_{i,t}$. This also implies that measured relative economic profitability ($\pi^{R}_{i,t}$) is not influenced by quality adjustment. Also, we can produce measures of unit-specific quality adjusted output indices over time, $Y^{US,Q}_{i,t}$ and implicit quality index over time ($Q^{US}_{i,t}$) which measures the implied difference in unit-specific quality over time as $Q^{US}_{i,t} = Y^{US,Q}_{i,t} / Y^{US}_{i,t}$. Therefore, estimates of temporal quality adjusted outputs and output prices can also be expressed as $Y^{US,Q}_{i,t} = Q^{US}_{i,t} Y^{US}_{i,t}$ and $P^{US,Q}_{i,t} = P^{US}_{i,t} \big/ Q^{US}_{i,t}$. Thus, the quality adjusted unit-specific TFP and TPP over time can be expressed as $TFP^{US,Q}_{i,t} = Q^{US}_{i,t} TFP^{US}_{i,t}$ and $TPP^{US,Q}_{i,t} = TPP^{US}_{i,t} / Q^{US}_{i,t}$, while the unit-specific economic profitability over time as $\pi^{US}_{i,t} = TFP^{US,Q}_{i,t} TPP^{US,Q}_{i,t}$.

As stated above, our adjustment of output prices and quantities for quality implies that any changes in the quality adjusted TPP index over time are balanced by an equivalent proportional change in the quality adjusted TFP index over time, thereby keeping the measurement of economic profitability unaffected by quality adjustment. We wish to emphasize that this is a reasonable assumption. Firstly, taking account of quality should not effect our underlying definition of economic profitability as turnover divided by economic costs. Secondly, it reflects the mathematical necessity that if turnover is constant, allowing for increases in output resulting from quality improvements, must result in a perfectly proportional reduction in output prices. Therefore, by adjusting TFP and TPP measures for quality keeping economic profitability unchanged, we are able to offer an alternative decomposition of unit-specific profitability growth, which will more properly attribute quality improvements to productivity improvement, rather than to over estimated improvements in price performance that would result from a quality-unadjusted measure. Moreover, as we will illustrate, this allows a further decomposition of equation (8) into the catch-up in quality regarding productivity and price performance achieved by less productivity firms and the quality growth in productivity and price performance of the base firm in a multilateral context.

Given the derivation of the spatial implicit output quality index ($Q_{i,t}^{S}$) which measures the implied difference in quality relative to the base firm, we are able to construct measures of the catch-up in quality, $Q_{i,t}^{C}$, as a ratio of the spatial implicit quality index for any firm i to the base firm between year 1 and t, $Q_{i,t}^{C} = \frac{Q_{i,t}^{S}}{Q_{i,1}^{S}}$. Moreover, given the availability of $Q_{i,t}^{S}$, $Q_{i,t}^{US}$ and $Q_{i,t}^{R}$ the catch up in quality can be expressed in a similar manner to what was demonstrated in equation (7):

$$Q_{i,t}^{C} = \frac{Q_{i,t}^{S}}{Q_{i,1}^{S}} = \frac{\dfrac{Q_{i,t}^{R}}{Q_{b,t}^{R}}}{\dfrac{Q_{i,1}^{R}}{Q_{b,1}^{R}}} = \frac{\dfrac{Q_{i,t}^{R}}{Q_{i,1}^{R}}}{\dfrac{Q_{b,t}^{R}}{Q_{b,1}^{R}}} = \frac{Q_{i,t}^{US}}{Q_{b,t}^{US}} \tag{9}$$

Rearranging (9), we can express the unit-specific quality index of any firm i over time as a function of the catch-up in quality to the base firm and the quality improvement of the base firm, $Q_{i,t}^{US} = Q_{i,t}^{C} Q_{b,t}^{US}$.

Given our discussion of our approach to quality adjustment, the decomposition of firm specific economic profitability change detailed in (8) can now be extended, in the multilateral context, as follows:

$$\pi_{i,t}^{US} = \pi_{i,t}^{C}\pi_{b,t}^{US} = (TFP_{i,t}^{C}TFP_{b,t}^{US})(TPP_{i,t}^{C}TPP_{b,t}^{US})$$

$$= \left(TFP_{i,t}^{US,Q}\right)\left(TPP_{i,t}^{US,Q}\right) = \left(TFP_{i,t}^{C,Q}TFP_{b,t}^{US,Q}\right)\left(TPP_{i,t}^{C,Q}TPP_{b,t}^{US,Q}\right) \quad (8')$$

$$= \left(TFP_{i,t}^{C}Q_{i,t}^{C}\right)\left(TFP_{b,t}^{US}Q_{b,t}^{US}\right)\left(\frac{TPP_{i,t}^{C}}{Q_{i,t}^{C}}\right)\left(\frac{TPP_{b,t}^{US}}{Q_{b,t}^{US}}\right)$$

Thus, as in (8), in the first line of (8'), unit-specific economic profitability change, $\pi_{i,t}^{US}$, can be decomposed as a function of the quality unadjusted catch-up in productivity, $TFP_{i,t}^{C}$ and the productivity growth of the benchmark firm, $TFP_{b,t}^{US}$ and the quality unadjusted catch-up in price performance, $TPP_{i,t}^{C}$ and the price performance growth of the benchmark firm, $TPP_{b,t}^{US}$ By including quality in TFP and TPP measures, in the second line of equation (8'), the unit-specific economic profitability over time can be expressed as a function of the unit-specific quality adjusted productivity, $TFP_{i,t}^{US,Q}$ and quality-adjusted price performance change, $TPP_{i,t}^{US,Q}$. This can be further decomposed as a function of the quality adjusted catch-up in productivity, $TFP_{i,t}^{C,Q}$ and the quality adjusted productivity growth of the benchmark firm, $TFP_{b,t}^{US,Q}$ and the quality adjusted catch-up in price performance, $TPP_{i,t}^{C,Q}$ and the quality adjusted price performance growth of the benchmark firm, $TPP_{b,t}^{US,Q}$. Finally, the third line of (8') demonstrates the impact of quality in TFP and TPP measures over time. Thus, unit-specific economic profitability change, $\pi_{i,t}^{US}$, can be decomposed as a function of the quality unadjusted catch-up in productivity, $TFP_{i,t}^{C}$, the catch-up in quality regarding productivity, $Q_{i,t}^{C}$ and the quality-unadjusted productivity and quality performance over time of the benchmark firm, $TFP_{b,t}^{US}$ and $Q_{b,t}^{US}$ and the quality unadjusted catch-up in price performance, $TPP_{i,t}^{C}$ the catch-up in quality regarding price performance, $1/Q_{i,t}^{C}$ and the price performance and quality growth of the benchmark firm, $TPP_{b,t}^{US}$ and $1/Q_{b,t}^{US}$. If $TFP_{i,t}^{C} > 1$ or $TPP_{i,t}^{C} > 1$, then firm i improved its productivity or price performance relative to the base firm from year 1 to t, whereas a value lower than 1 indicates that productivity or price performance of firm i has declined relative to that of the base firm. If $Q_{i,t}^{C} > 1$ or $1/Q_{i,t}^{C} < 1$, then the firm *i* improved its quality regarding productivity or price performance relative to the base firm from year 1 to year t, whereas a value lower than 1 indicates that relative quality regarding productivity or price performance of firm i has declined relative to that of the base firm.

Finally, the decomposition of the unit specific economic profitability over time in equation (8') can be visualized in Figure 1. As adjustments for quality affect the productivity and price performance measures leaving the measured economic profitability unchanged, the unit-specific profitability growth can be expressed as a function of the unit-specific quality adjusted productivity and quality-adjusted price performance change. This can be further decomposed as a function of the quality adjusted catch-up in productivity, and the quality adjusted productivity growth of the benchmark firm, and the quality adjusted catch-up in price performance, and the quality adjusted price performance growth of the benchmark firm. The inclusion of quality in our analysis allows us to finally decompose unit-specific economic profitability change as a function of the quality unadjusted catch-up in productivity, the catch-up in quality regarding productivity, and the quality-unadjusted productivity and quality performance over time of the benchmark firm, and the quality unadjusted catch-up in price performance, the catch-up in quality regarding price performance, and the price performance and quality growth of the benchmark firm.

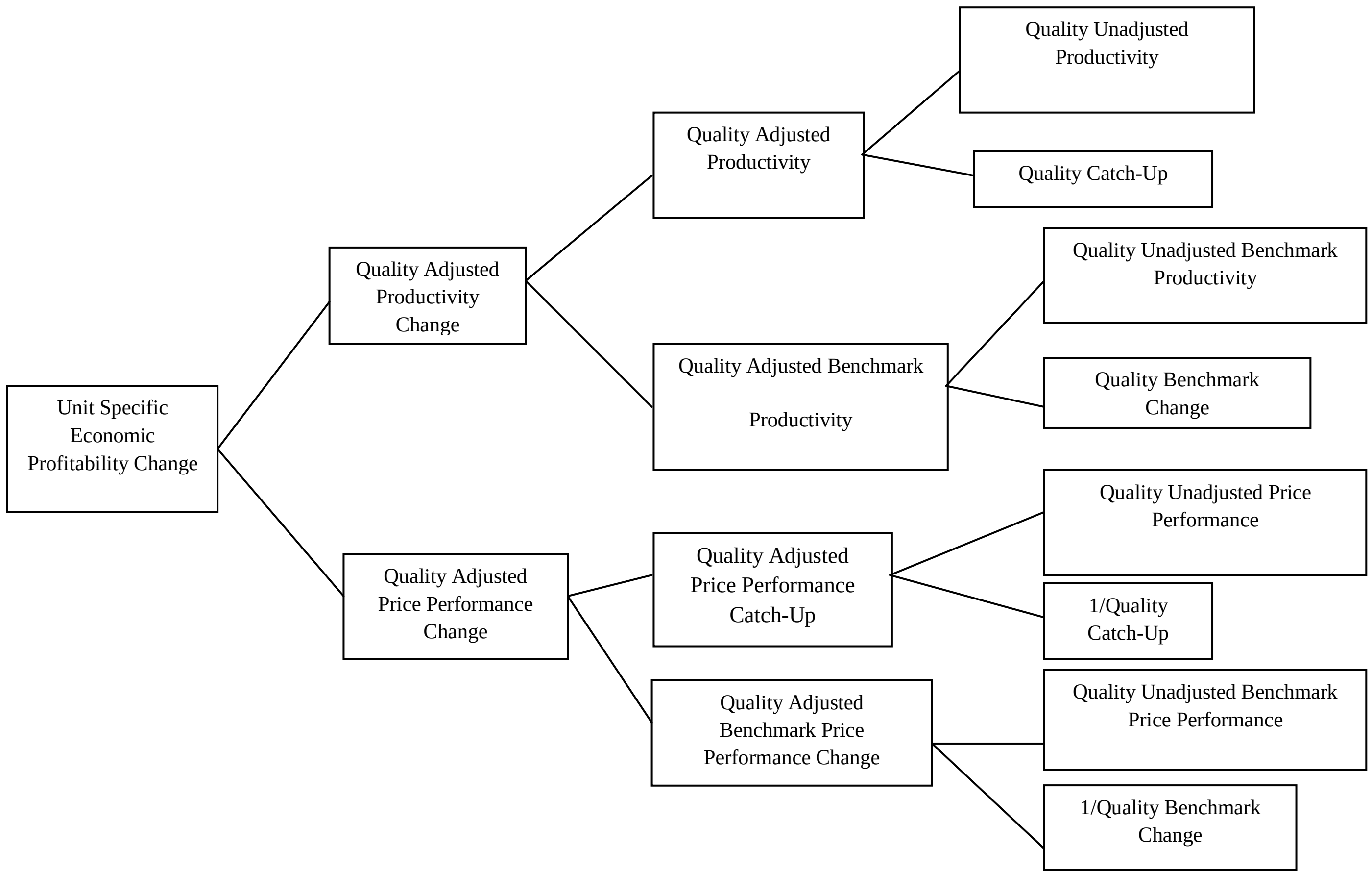

Figure 1 Decomposition of Unit Specific Economic Profitability Change after Adjustments for Quality

2.3. Multilateral Productivity, Price Performance and Profitability Computations In Practice

2.3.1. Chained Unit-specific Productivity, Price Performance and Profitability Over Time

In this section we define chained unit-specific profitability, productivity and price performance growth. Temporal Fisher output and input indexes between two time periods 1 and t, where 1 is the base period in the case of m outputs and n inputs for a firm i are respectively, $Y_{i,t}$ and $X_{i,t}$, :

$$Y_{i,t} = [\frac{\sum_{m=1}^{M} P_1^m Y_t^m}{\sum_{m=1}^{M} P_1^m Y_1^m} \times \frac{\sum_{m=1}^{M} P_t^m Y_t^m}{\sum_{m=1}^{M} P_t^m Y_1^m}]^{\frac{1}{2}} \qquad X_{i,t} = [\frac{\sum_{n=1}^{N} W_1^n X_t^n}{\sum_{n=1}^{N} W_1^n X_1^n} \times \frac{\sum_{n=1}^{N} W_t^n X_t^n}{\sum_{n=1}^{N} W_t^n X_1^n}]^{\frac{1}{2}} \tag{10}$$

where Y_t^m and Y_1^m denote the quantities for the mth output for periods t and 1 respectively, whereas X_t^n and X_1^n present the quantities for the nth inputs for periods t and 1 respectively. Moreover, P_t^m and P_1^m are the prices for mth output, while W_t^n and W_1^n denote the input prices. The Fisher output and input indexes of a firm i between two time periods, 1 and t, can also be expressed as the geometric means of Laspeyers and Paasche output and input indexes. A temporal Fisher productivity index, $TFP_{i,t}$ is constructed as a ratio of Fisher output index relative to Fisher input index, which takes the value 1 in the year 1 (base period):

$$TFP_{i,t} = \frac{Y_{i,t}}{X_{i,t}} \tag{11}$$

A temporal Fisher productivity index can be used in the unchained form denoted above or in a chained form where weights are more closely matched to pair-wise comparisons of observations (Diewert & Lawrence, 2006). The unit-specific output and input indices are thus chained indices, $Y_{i,t}^{CH}$ and $X_{i,t}^{CH}$ between observations 1 and t which are given by:

$$Y_{i,t}^{CH} = 1 \times Y_{i,1,2} \times Y_{i,2,3} \times ... \times Y_{i,t-1,t} \qquad X_{i,t}^{CH} = 1 \times X_{i,1,2} \times X_{i,2,3} \times ... \times X_{i,t-1,t} \tag{12}$$

The unit-specific productivity of a firm i over time can be similarly calculated as a chained index, although it can be equivalently calculated as a ratio of the chained unit-specific output and input indices over time, $Y_{i,t}^{CH}$ and $X_{i,t}^{CH}$:

$$TFP_{i,t}^{CH} = \frac{Y_{i,t}^{CH}}{X_{i,t}^{CH}} \tag{13}$$

Given these chained unit-specific indexes, we can proceed to derive related TPP and Profitability indices as in Saal and Parker (2001). To derive TPP index we firstly express unit-specific turnover at period t relative to the base year 1 as $R_{i,t}^{US} = R_{i,t} / R_{i,1}$. The chained unit-specific aggregate output price index, $\left(P_{i,t}^{CH}\right)$ is then calculated as $P_{i,t}^{CH} = R_{i,t}^{US} \big/ Y_{i,t}^{CH}$. Similarly, we express unit-specific nominal economic costs at period t relative to the base year 1 as $C_{i,t}^{US} = C_{i,t} / C_{i,1}$. The chained unit-specific aggregate input price index, $\left(W_{i,t}^{CH}\right)$ is then calculated as $W_{i,t}^{CH} = C_{i,t}^{US} \big/ X_{i,t}^{CH}$. Finally, a chained unit-specific TPP index for any firm *i* over time, $\left(TPP_{i,t}^{CH}\right)$ can be obtained as:

$$TPP_{i,t}^{CH} = \frac{\dfrac{R_{i,t}^{US}}{Y_{i,t}^{CH}}}{\dfrac{C_{i,t}^{US}}{X_{i,t}^{CH}}} = \frac{P_{i,t}^{CH}}{W_{i,t}^{CH}} \tag{14}$$

Therefore, a chained unit-specific economic profitability index at period t relative to the base year 1 , $\pi_{i,t}^{CH}$ is calculated as the product of a chained index of unit-specific total factor productivity over time, $TFP_{i,t}^{CH}$ and a chained unit-specific index of total price performance over time, $TPP_{i,t}^{CH}$.

2.3.2. Spatial Productivity, Price Performance and Profitability

In the previous section, we used a chained Fisher index to measure profitability, productivity and price performance of any firm between period 1 and period t. In this section, we derive a multilateral Fisher index to measure profitability, productivity and price performance across companies at any given year (multilateral spatial comparisons). When the price and quantities across different companies are compared, it is important that such comparisons are undertaken for every pair of companies being considered (multilateral comparisons). However, in order to achieve consistency between all the pairs of comparisons we need to derive multilateral indexes that fulfill the property of transitivity. Internal consistency (transitivity) implies that a direct comparison between two firms gives the same result when comparing indirectly these two firms through a third firm.

Therefore, binary Fisher output and input indices between two firms i and j, $Y_{i,j}$ and $X_{i,j}$ can be converted into multilateral consistent transitive indices by applying the EKS method developed by Elteto-Koves (1964) and Szulc (1964) to derive transitive Fisher indices (see Caves, Christensen and Diewert (1982a), Diewert and Lawrence (2006) and Ball et al (2001) for a discussion on multilateral transitive indices). We therefore derive transitive Fisher output and input indices using the EKS method, which is equivalent to taking the geometric mean of the *I* possible direct and indirect (through any possible 3rd firm *k*) binary Fisher comparisons of firms *i* and *j*. The resulting Fisher output and input indices, Y_{ij}^S and X_{ij}^S therefore fulfill the transitivity property:

$$Y_{ij}^S = \prod_{k=1}^{I} \left[Y_{ik} \times Y_{kj} \right]^{\frac{1}{I}} \qquad X_{ij}^S = \prod_{k=1}^{I} \left[X_{ik} \times X_{kj} \right]^{\frac{1}{I}} \tag{15}$$

Adopting the terminology of the price index literature (Hill, 2004) we refer to these multilateral output and input indices as spatial indices, as they provide spatially consistent measures across all firms.

The spatial total factor productivity Fisher index for a firm i relative to firm j, $TFP_{i,j}^S$, can then be constructed as the ratio of the spatial Fisher output index relative to spatial Fisher input index:

$$TFP_{ij}^S = \frac{Y_{ij}^S}{X_{ij}^S} \tag{16}$$

While we can generate the $I \times I$ possible transitive spatial output, input and productivity indexes between all firms, transitivity also implies that all meaningful information with regard to relative productivity is available in a subset of only I of these indices. Thus, if we arbitrarily choose one firm as a base firm and set $j = b$, then each spatial measure, is a measure of firm i relative to the chosen base firm and we can also simplify notation such that $TFP_{i,b}^{S} = TFP_{i}^{S}, Y_{i,b}^{S} = Y_{i}^{S}, X_{i,b}^{S} = X_{i}^{S}$. Therefore, productivity relative to the base firm's productivity can be expressed as:

$$TFP_{i}^{S} = \frac{Y_{i}^{S}}{X_{i}^{S}} \tag{17}$$

However, this simplification comes at no loss of generality as another spatial productivity measure between any given firms can simply be calculated as $TFP_{i,j}^{S} = TFP_{i}^{S} / TFP_{j}^{S}$. Similarly, $Y_{i,j}^{S} = Y_{i}^{S} / Y_{j}^{S}$ and $X_{i,j}^{S} = X_{i}^{S} / X_{j}^{S}$.

If spatial comparisons are available for each of T time periods indexed by t, and we assume the same base firm in all years, we can define the spatial productivity of firm i relative to firm b at time t as:

$$TFP_{i,t}^{S} = \frac{Y_{i,t}^{S}}{X_{i,t}^{S}} \tag{18}$$

We now turn our discussion to the construction of the spatial total price performance index, $\left(TPP_{i,t}^{S}\right)$. Firstly, we express turnover of a firm i relative to the base firm as $R_{i,t}^{S} = R_{i,t} \big/ R_{b,t}$. The spatially consistent aggregate output price index, $\left(P_{i,t}^{S}\right)$ is then calculated as $P_{i,t}^{S} = R_{i,t}^{S} \big/ Y_{i,t}^{S}$. Similarly, we express nominal economic costs of a firm i relative to the base firm as $C_{i,t}^{S} = C_{i,t} \big/ C_{b,t}$. The spatially consistent aggregate input price index, $\left(W_{i,t}^{S}\right)$ is then calculated as $W_{i,t}^{S} = C_{i,t}^{S} \big/ X_{i,t}^{S}$. Finally, a spatially consistent TPP index of any firm i relative to the base firm at any given time t, $\left(TPP_{i,t}^{S}\right)$ can be obtained as:

$$TPP_{i,t}^{S} = \frac{\dfrac{R_{i,t}^{S}}{Y_{i,t}^{S}}}{\dfrac{C_{i,t}^{S}}{X_{i,t}^{S}}} = \frac{P_{i,t}^{S}}{W_{i,t}^{S}} \tag{19}$$

Therefore, a spatial economic profitability index at time t, $\pi_{i,t}^{S}$ is calculated as the product of an index of spatial total factor productivity for firm *i* relative to the base firm *b*, $TFP_{i,t}^{S}$ and a spatial index of total price performance between firm *i* and the base firm *b*, $TPP_{i,t}^{S}$.

2.3.3. Relative Productivity, Price Performance and Profitability Change Over Time

In order to simultaneously measure and decompose the profitability growth of any firm in the sample across time and relative to other firms, in practice it is necessary to reconcile the spatial profitability measures defined above with the underlying unit-specific chained profitability of each firm. This is because while section 2 has theoretically demonstrated that relative productivity measures can be expressed as a function of unit-specific and spatial productivity measures, this is not as straightforward in a multilateral empirical application. Thus, as demonstrated by Hill (2004) we cannot, in practice, derive multilateral measures of the productive change of any firm *i* relative to the base firm, which can satisfy both spatial and temporal consistency.[2]

We have therefore chosen to pursue measures of relative productivity change over time that guarantee spatial consistency, as this approach is most consistent in the regulatory application we demonstrate below. Thus regulators in comparative or yard stick regulatory regimes typically employ cross section techniques to measure differences in productivity or efficiency across firms (relative comparative performance) and therefore use what are, in fact, spatial performance measures to inform their decision with regard to appropriate regulated prices. Thus, as our applied relative performance measures retain spatial consistency by construction, the relative performance indices will yield comparative performance measures that are consistent with regulatory practice in any given year. However, because our relative measures will also allow intertemporal analysis across firms, they have the advantage of allowing a more detailed analysis of firm performance change over time, which is not possible with a spatial index alone. .

[2] Spatially consistency implies that each year's relative productivity measures do not depend on the other years in the comparison and temporal consistency implies that each firm's productivity estimates do not depend on the number of observations in the time series

Given these arguments, we follow Hill's approach (2004). Therefore, firm i's relative productivity change over time ($TFP_{i,t}^{R}$) is determined as the geometric average of the *I* alternative potential estimates of relative productivity, as derived by employing the chained time trends and spatial productivities of all the *I* firms in the sample:

$$TFP_{i,t}^{R} = \left[\prod_{j=1}^{I} \left[(TFP_{j,t}^{CH} \times TFP_{j,1}^{S}) \times \frac{TFP_{i,t}^{S}}{TFP_{j,t}^{S}} \right] \right]^{\frac{1}{I}} \quad (20)$$

Thus, when i = j, $TFP_{i,t}^{R}$ can be simply expressed as the product of the firm's own chained productivity index and its spatial productivity measure in year 1: $TFP_{i,t}^{R} = TFP_{i,t}^{CH} TFP_{i,1}^{S}$. In contrast, for the alternative *I*-1 estimates when, $i \neq j$. $TFP_{i,t}^{R}$ can also be expressed as a function of any other firm *j*'s relative productivity index calculated as $TFP_{j,t}^{R} = TFP_{j,t}^{CH} TFP_{j,1}^{S}$, and the spatial productivity of firm i relative to firm j, which given the definition of our spatial productivity measures, can be expressed as $\frac{TFP_{i,t}^{S}}{TFP_{j,t}^{S}}$. Thus, rather than relying on a single one of these potential estimates, the definition of $TFP_{i,t}^{P}$ in (20) employs all available spatial and chained productivity estimates to provide an arguably superior geometric average estimate of $TFP_{i,t}^{R}$. We can similarly derive measures of the relative output and input indices over time, $Y_{i,t}^{R}$ and $X_{i,t}^{R}$.

Following our approach in (4) these relative measures are indices of any firm *i* measured relative to the base firm in the base year. Construction of consistent price, and TPP indices can therefore be accomplished by firstly expressing turnover of firm *i* relative to the base firm at the base year 1 as $R_{i,t}^{R} = R_{i,t} / R_{b,1}$. The relative aggregate output price index over time, $\left(P_{i,t}^{R}\right)$ is then calculated as $P_{i,t}^{R} = R_{i,t}^{R} / Y_{i,t}^{R}$. Similarly, we express nominal economic costs of a firm *i* relative to the base firm at the base year 1 as $C_{i,t}^{R} = C_{i,t} / C_{b,1}$. The relative aggregate input price index over time, $\left(W_{i,t}^{R}\right)$ is then calculated as $W_{i,t}^{R} = C_{i,t}^{R} / X_{i,t}^{R}$. Finally, a relative TPP index of any firm *i* relative to the base firm at the base year 1, $\left(TPP_{i,t}^{R}\right)$ can be obtained as:

$$TPP_{i,t}^{R} = \frac{\dfrac{R_{i,t}^{R}}{Y_{i,t}^{R}}}{\dfrac{C_{i,t}^{R}}{X_{i,t}^{R}}} = \frac{P_{i,t}^{R}}{W_{i,t}^{R}} \qquad (21)$$

As a result, a relative economic profitability index, $\pi_{i,t}^{R}$ can be calculated as the product of an index of relative total factor productivity for firm *i* relative to the base firm *b* at base year 1, $TFP_{i,t}^{R}$ and a relative index of total price performance between firm *i* and the base firm *b* at the base year 1, $TPP_{i,t}^{R}$.

In order to achieve our ultimate goal of decomposing unit specific profit growth in the multilateral context, as demonstrated in (8) in the bilateral context, we must finally derive unit specific indices which are consistent with the relative indices developed in (20) and (21). We therefore calculate a consistent measure of unit-specific productivity over time, which can be obtained as $TFP_{i,t}^{US} = \frac{TFP_{i,t}^{R}}{TFP_{i,1}^{R}}$. Similarly, consistent measures of unit-specific output and input growth are respectively $Y_{i,t}^{US} = \frac{Y_{i,t}^{R}}{\mathrm{Y}_{i,1}^{R}}$ and $X_{i,t}^{US} = \frac{X_{i,t}^{R}}{\mathrm{X}_{i,1}^{R}}$. In an analogous manner, consistent measures of unit-specific TPP output price, input price and economic profitability indexes are respectively, $TPP_{i,t}^{US} = \frac{TPP_{i,t}^{R}}{TPP_{i,1}^{R}}$, $P_{i,t}^{US} = \frac{P_{i,t}^{R}}{\mathrm{P}_{i,1}^{R}}$, $W_{i,t}^{US} = \frac{W_{i,t}^{R}}{\mathrm{W}_{i,1}^{R}}$ and $\pi_{i,t}^{US} = TFP_{i,t}^{US} TPP_{i,t}^{US}$.

Given our modeling decision to maintain spatial consistency at the cost of temporal consistency, and the subsequent employment of the geometric average of the *I* alternative potential relative indicators as appropriate unit specific relative productivity, output and input indices, we must note that the unit-specific chained temporal indexes will, by construction, not be perfectly consistent with the unit specific temporal indexes constructed from the multilateral relative indices. Nevertheless, it can be readily mathematically demonstrated that the geometric average of the *I* chained unit specific temporal indices and those derived from the relative indices detailed in equations (25) and (26) are equal. Thus, for example, if we take the geometric average across all firms I in the sample, then

$\left[\prod_{i=1}^{I}\left(TFP_{i,t}^{CH}\right)\right]^{\frac{1}{I}} = \left[\prod_{i=1}^{I}\left(TFP_{i,t}^{US}\right)\right]^{\frac{1}{I}}$, and $\left[\prod_{i=1}^{I}\left(TPP_{i,t}^{CH}\right)\right]^{\frac{1}{I}} = \left[\prod_{i=1}^{I}\left(TPP_{i,t}^{US}\right)\right]^{\frac{1}{I}}$. This implies that while our approach to deriving the relative indicators necessary to decompose unit-specific trends in firm performance can result in minor deviations from the temporal trends implied by the unit-specific chained indices, we can nonetheless be fully confident that on average, the unit specific estimates are consistent with the underlying chain-based estimates of temporal change in firm performance. We therefore, focus on these average estimates and their decomposition in our results below.

This section has specified a methodology to allow the empirical application of unit-specific, spatial and relative economic profitability indices and their decomposition into unit-specific, spatial and relative productivity and price performance indices in a multilateral setting by reconciling together temporal chained and spatial indices, following Hill's approach (2004). Moreover, we have demonstrated that these estimates are not only spatially consistent, but are also, on average, consistent with alternative unit-specific chained indices of temporal performance change. Thus, this section has demonstrated an appropriate methodology to allow for decompositions of profitability indices in a multilateral setting, thereby extending the approach illustrated in equations (1), (2) and (3) in the binary context. Consequently, we are able to consistently decompose unit specific profitability change as a function of the profitability growth of a base firm and profitability catch-up relative to that firm over time, which can be further decomposed as a function of the productivity and price performance of a base firm and productivity and price performance catch-up relative to that firm over time, in a multilateral setting, as illustrated in equation (8) in the binary context. Finally, it can be easily proven that by adjusting output with quality we can also extend equation (8') in a multilateral setting.

4. Data

Our model includes separate outputs for water and sewerage services, and the three inputs, capital, labor and other inputs. The data covered are for the period 1991-2008 for a balanced panel of 10 Water and Sewerage companies (WaSCs). Water connected properties and sewerage connected properties are the proxies for water and sewerage output and are drawn from the companies' regulatory returns to Ofwat, which are used to construct the output indices. These binary output indices then formed the basis of constructing fully spatially consistent output indices with the EKS method. Finally, spatially consistent aggregate output price indices were constructed as the ratio of relative aggregate turnover in nominal terms to this spatial aggregate output index, as discussed above.

Our 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. Instead, we accept the year ending 2006 MEA valuations as our base value, and use net investment in real terms to update this series for earlier and later years. 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 and Parker's (2001) approach, we 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, and construct 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.

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. Other costs in nominal terms were defined as the difference between operating costs and total labour costs.[3] Given the absence of data allowing a more refined break out 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. Given these input quantity and price measures, we are able to calculate indices of unit-specific, spatial and relative input usage discussed above. As total nominal economic costs are obtained as the sum of total capital costs, labour costs and other costs in nominal terms, division of this sum by the unit-specific, spatial and relative input index, allows the construction of unit-specific, spatial and relative input price indices. Finally, economic profits are calculated as the difference between turnover and calculated economic costs.

Following Saal and Parker (2001) the drinking water quality index is calculated as the ratio of the average percentage of each WaSC's water supply zones that are fully compliant with key water quality parameters, relative to the average compliance percentage for England and Wales in 1991. 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 data were drawn from the DWI's annual reports for drinking water quality for the calendar years ending 1991-2007[4]. 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

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[3] 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.

[4] 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.

reasons and cost reasons or based on 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 report results for the drinking water quality based on the six water quality parameters[5] that Ofwat also employs in his assessment and reflect how well treatment works and distribution systems are operated and maintained (Ofwat, 2006).

The sewage treatment quality index is defined as a weighted index of the percentage of connected population for which sewage receives primary treatment and the percentage of population for which sewage receives at least secondary treatment. It also implicitly includes the percentage of connected population for which sewage is not treated with a zero weight. This data choice reflects both the availability of consistent data capturing quality trends for the entire 1991-2008 period, and does clearly capture substantial increases in sewage treatment levels, particularly in the earlier part of the sample period. The sewage treatment data were taken from *Waterfacts* for the first years 1990-91 to 1995-96 and the companies' regulatory returns for the fiscal years 1996-97 to 2007-08. Moreover, we henceforward refer to data based on the ending year of the fiscal years.

It is clearly necessary to employ a weighted index of these measures as both the quality and costs of higher treatment levels exceed those associated with non treatment or primary treatment alone. We therefore endeavoured to construct a cost based weighting system, although the necessary data to accomplish this was relatively limited. However, we were able to calculate relative cost measures based on the ratio of sewerage treatment costs to volumes of sewerage treatment, using two alternative cost estimates available from company regulatory returns. One of these alternative estimates was based on total sewerage treatment functional expenditure and direct costs for all treatment works, while the other was based on total sewage treatment

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[5] The six water quality parameters, which form the Operational Performance Index (OPI) are iron, manganese, aluminium, turbidity, faecal coliforms and trihalomethanes. The resulting drinking water quality index suggests an increase in quality of 10.3 percent between 1991 and 2008 after aggregating the data for all WaSCs.

costs for large treatment works only. These estimates suggest that higher levels of treatment are 1.68 to 2.40 times more costly than primary treatment only. Given this estimate range, we chose to weight the percentage of population receiving secondary treatment of sewage or more twice as much as the percentage receiving primary treatment only. While admittedly, somewhat ad hoc, we emphasize there is some empirical evidence to support these weights. We note that it is straightforward to demonstrate that the resulting weighted quality index is nested between an index based solely on the percentage of population receiving at least primary sewage treatment, which would underestimate gains in sewage treatment quality, and one based solely on the percentage of population receiving at least secondary sewage treatment, which would overestimate gains in sewage treatment quality.

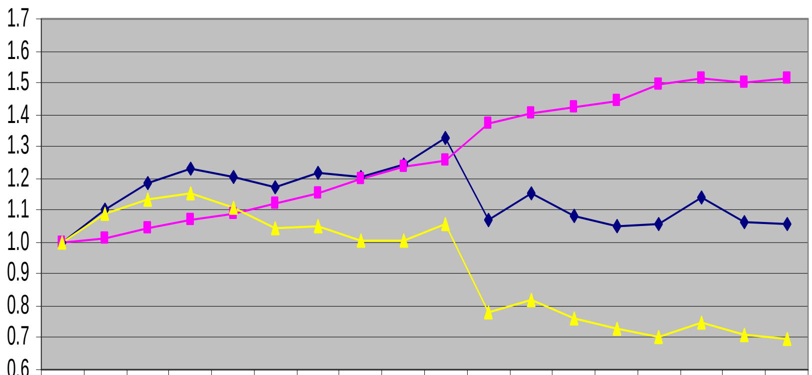
5. Results from productivity, price performance and profitability after controlling for quality

The above spatial and relative profitability, productivity and price performance measures were defined relative to the base firm in the sample. However, if the base firm is defined as the firm with the highest productivity in the sample, then each firm's productivity, prices and profits will be relative to this best practice or benchmark firm.[6] In this section we first report geometric average measures of unit-specific profitability, productivity and price performance. Consequently, we decompose theses changes into an average catch-up component and the performance of the benchmark firm as illustrated in equation (8).

Figure 2 illustrates the decomposition of unit-specific economic profitability change into quality adjusted unit-specific productivity and price performance change over the period 1991-2008. The results indicate that between 1991 and 2008, average economic profitability increased by 5.9%, which was attributed to a significant improvement in TFP of 51.7% and a reduction in TPP of 30.2%. On average there

[6] We have not identified firms for confidentially reasons. The same firm is consistently found to have the highest spatial productivity estimates in all years, and is therefore modelled as the benchmark most productive firm in each year of our study Moreover, we note that his same firm was found to have the highest spatial productivity estimates in each year of the study regardless of whether we applied the spatially consistent Fisher indices provided in the main text, similar spatially consistent Tornqvist indices, or the multilateral translog index for WaSCs based on the Tornqvist index developed by Caves et al (1982a). Furthermore, there is little substantive difference between the results regardless of which method is employed.

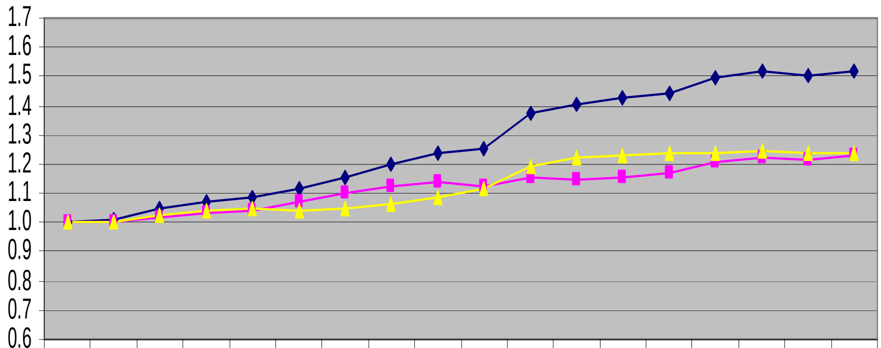
was a stable and substantial increase in TFP over time, while TPP followed an upward trend until 1994, which was interrupted in 1995, but was again followed by a substantial increase between 1999 and 2000. We note that during the years 1991-1995, average economic profitability increased due to increases in TPP which was substantially greater than TFP growth. As documented in previous studies, Ofwat's tightening of price caps in the 1994 price review decreased the growth in real output prices and therefore resulted in a downward trend for both TPP and economic profitability until 1998, while TFP continued to improve significantly. After 2000, reduced output prices caused TPP to dramatically decline, and its value remained consistently below 1 after 2000. This indicates that regulatory price changes implemented after 2000 caused the price performance of firms to fall substantially below its level in 1991. Moreover, average unit-specific TPP followed a downward trend except for 2006, when output prices were allowed to momentarily rise in the first year of the 2006-10 regulatory period. Unsurprisingly, given the dramatic fall in price performance after 2000, average economic profitability also substantially declined, even if TFP continued to follow a steady upward trend, which was only momentarily interrupted in 2007. Thus, in the post 2000 period, trends in temporal economic profitability followed the trend of TPP, indicating that changes in price performance were a significant determinant of changes in economic profitability.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Economic Profitability	1.000	1.102	1.186	1.234	1.205	1.170	1.217	1.206	1.244	1.326	1.069	1.150	1.082	1.050	1.054	1.138	1.064	1.059
Quality Adjusted TFP	1.000	1.011	1.046	1.067	1.086	1.119	1.156	1.197	1.236	1.254	1.370	1.401	1.424	1.442	1.493	1.516	1.501	1.517
Quality Adjusted TPP	1.000	1.090	1.134	1.156	1.109	1.045	1.052	1.008	1.007	1.058	0.780	0.821	0.760	0.729	0.706	0.750	0.709	0.698

Figure 2 Decomposition of Average Unit Specific Profitability into Average Quality Adjusted Unit Specific TFP and TPP

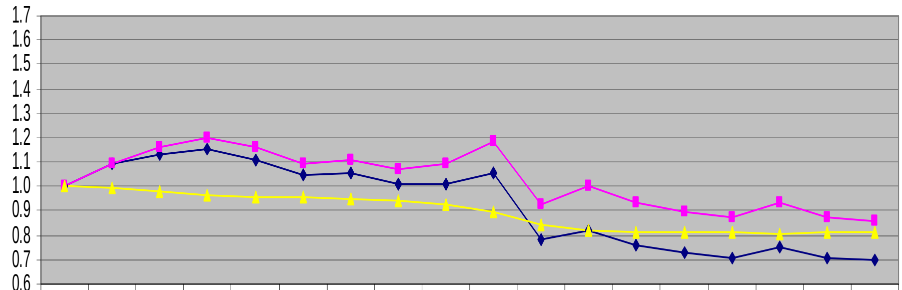
Moreover, Figure 3 depicts the decomposition of quality adjusted average TFP change into quality unadjusted average TFP change and quality change. High capital investment programs to improve quality conditions since privatization had a positive impact on quality adjusted output growth and consequently, quality adjusted TFP increased more than quality unadjusted TFP. Over the whole regulatory period average quality adjusted TFP improved by 51.7%, whereas average quality unadjusted TFP improved by only 22.9% implying that average estimated quality change amounted to 23.4%. Much of the measured quality improvement occurred during the years 1991-2002 and quality showed its highest level of improvement in the years 1999 and 2002. Thus, by 2002, average quality improved by 22% resulting in an increase in average quality adjusted TFP of 40.1% and exceeded average quality unadjusted TFP which improved by only 14.8%. After 2003, on average there were small improvements in quality and thus, small changes in the quality adjusted TFP growth rate, whereas in the last two years of our study average quality followed a slightly decline trend. Nevertheless productivity still continued to improve in this later period, suggesting that firms were able to achieve productivity improvements by reducing input usage.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Quality Adjusted TFP	1.000	1.011	1.046	1.067	1.086	1.119	1.156	1.197	1.236	1.254	1.370	1.401	1.424	1.442	1.493	1.516	1.501	1.517
Quality Unadjusted TFP	1.000	1.006	1.021	1.029	1.039	1.072	1.100	1.126	1.140	1.120	1.150	1.148	1.157	1.168	1.209	1.220	1.215	1.229
Quality	1.000	1.006	1.025	1.037	1.045	1.044	1.051	1.063	1.084	1.120	1.191	1.220	1.231	1.234	1.235	1.243	1.236	1.234

Figure 3 Decomposition of Average Unit Specific Quality Adjusted TFP Change into Average Unit-Specific TFP and Quality Change

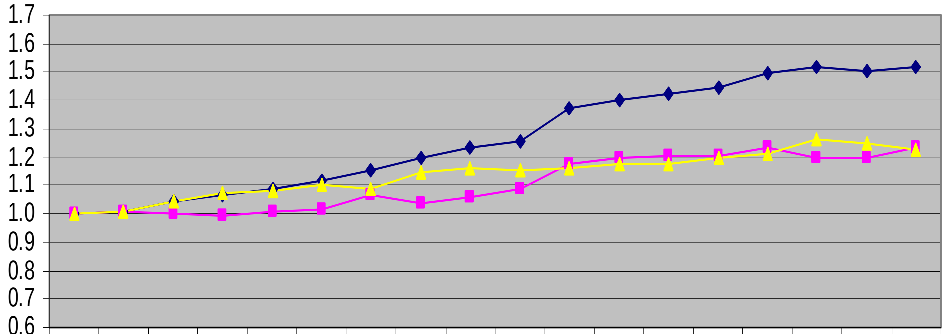
Figure 4 displays the decomposition of quality adjusted average unit-specific TPP change into quality unadjusted average TPP change and quality change. Since output prices are adjusted for quality as we discussed in section 2, on average the magnitude of change in quality adjusted TPP must exceed that of quality unadjusted TPP. We would therefore emphasize that the quality adjusted TPP index must also follow the general trend of the quality-unadjusted index, but it also must demonstrate a more significant decline in price performance, as it allows for the output enhancing impact of quality improvements. During the lax price cap period 1991-1994, increases in quality unadjusted TPP exceeded the quality adjusted TPP implying that increases in output prices were greater than the quality adjusted output prices. This upward trend was interrupted in 1995 followed by a downward trend until 1998, whereas during the years 1999-2000 average quality unadjusted TPP and quality adjusted TPP started to increase again. The tightened 1999 price review obliged the companies to reduce their output prices and the magnitude of the reduction in quality adjusted TPP was significantly greater than the quality unadjusted TPP on average. Between the years 2000 and 2001 there was a significant fall in average quality unadjusted TPP and quality adjusted TPP by 0.930/1.184 = 0.785 or 21.5% and 0.780/1.058 = 0.737 or 26.3% respectively. After 2001, there was a downward trend for average quality unadjusted and quality adjusted TPP except for the years 2002 and 2006, where new looser price caps were introduced. We note that after 1998, on average quality adjusted TPP took a value lower than 1 implying that after controlling for quality the reduction in quality adjusted output prices was greater than the quality unadjusted output prices and therefore, relative to 1991, by 2008 average quality adjusted TPP reduced by 30.2%, whereas average quality unadjusted TPP declined by 13.9%, implying that the impact of average quality in output prices and therefore in average TPP was approximately 19%. Thus, Figure 4 clearly suggests that, while quality improvements have contributed to the productivity performance of the WaSCs, they have also contributed negatively to their price performance.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Quality Adjusted TPP	1.000	1.090	1.134	1.156	1.109	1.045	1.052	1.008	1.007	1.058	0.780	0.821	0.760	0.729	0.706	0.750	0.709	0.698
Quality Unadjusted TPP	1.000	1.096	1.162	1.199	1.160	1.091	1.106	1.072	1.091	1.184	0.930	1.002	0.936	0.899	0.872	0.933	0.876	0.861
1/Quality	1.000	0.994	0.976	0.964	0.957	0.958	0.952	0.941	0.923	0.893	0.840	0.819	0.813	0.810	0.810	0.805	0.809	0.810

Figure 4 Decomposition of Average Units Specific Quality Adjusted TPP Change into Average Unit-Specific TPP and Quality Change

The decomposition of quality adjusted average unit-specific productivity growth into the quality adjusted productivity growth of the benchmark firm and average quality adjusted productivity catch-up is depicted in Figure 5. The figure clearly illustrates that until 1994 there were small or no catch up gains in quality-adjusted productivity by the average company since its productivity improved by 6.7%, while the benchmark company improved its productivity by 7.1%. In contrast, due to sharp increases in measure quality between 1996 and 2002, average quality adjusted TFP increased more rapidly than benchmark quality adjusted TFP, thereby allowing the average company to catch-up considerably, with catch up amounting to 19.5% of cumulative productivity growth for the average firm by 2002. Even after 2002 the average company achieved still significant levels of catch-up in quality adjusted productivity until 2005, which must be attributed to input usage reductions. Thus, relative to 1991 levels, by 2005, average quality adjusted productivity had increased by 49.3% and exceeded that of benchmark firm, which had improved by 21.2%, therefore indicating productivity catch-up of 23.2%. Moreover, the considerable increase in average profitability relative to the benchmark firm must be attributed to this catch up effect. Nevertheless, after 2005, when the relatively looser 2004 price review came into effect, high levels of productivity catch-up are no longer indicative of general productivity improvements, as average quality adjusted productivity levels were largely static after 2005. Instead, they reflect a substantial decline in the benchmark firm's productivity after 2006. Thus, our results may be interpreted as suggesting that after the 2004 price review, substantial productivity improvements were no longer occurring.

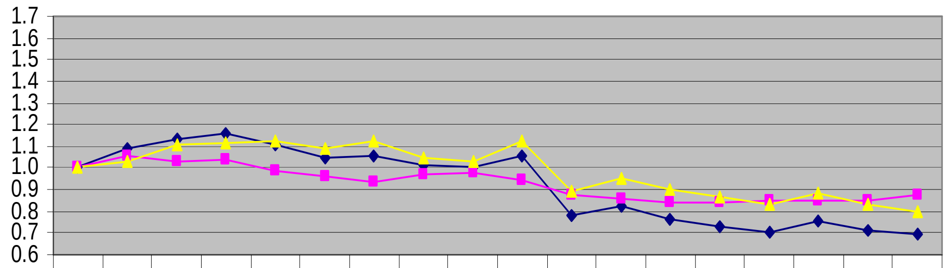


	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Unit-Specific	1.000	1.011	1.046	1.067	1.086	1.119	1.156	1.197	1.236	1.254	1.370	1.401	1.424	1.442	1.493	1.516	1.501	1.517
Catch-Up	1.000	1.006	1.000	0.996	1.007	1.013	1.063	1.041	1.061	1.088	1.179	1.195	1.208	1.202	1.232	1.199	1.199	1.233
Best	1.000	1.005	1.046	1.071	1.079	1.104	1.088	1.150	1.164	1.153	1.162	1.172	1.179	1.199	1.211	1.265	1.252	1.230

Figure 5 Decomposition of Average Unit-Specific Quality Adjusted TFP Change into Benchmark TFP Change and Average Catch-Up to the Benchmark Firm

The decomposition of quality adjusted average unit-specific TPP growth into the quality adjusted TPP growth of the benchmark firm and average quality adjusted TPP catch-up to the benchmark firm over time is depicted in Figure 6. Until 1994, quality adjusted average TPP growth exceeded benchmark TPP growth allowing an average catch-up in price performance of 3.6%. The tightened 1994 price review resulted in a substantial downward trend in quality adjusted average and benchmark TPP during the years 1996-1998, which was interrupted in 1999. We note that after 1995 and until the end of the period of study, quality adjusted benchmark TPP always exceeded quality adjusted average TPP. Moreover between 1995 and 2000 there was also a steady erosion of average price performance relative to benchmark price performance, as reflected in the catch up index from 0.990 to 0.942. This suggests a considerable rebalancing of regulatory price decisions in favour of the benchmark firm, which was even more dramatically extended with the implementation of the 1999 price review in 2001. Thus, despite a massive reduction in benchmark price performance from 1.123 to 0.889 of 1991 levels between 2000 and 2001, average price performance fell even further, as the decline of average quality adjusted TPP from 1.058 to 0.780 resulted in the catch up index falling from 0.942 to 0.878. It is therefore appropriate to interpret these results as substantial positive evidence demonstrating that both the 1994 and 1999 price reviews resulted in considerable movement to a regulatory price cap system consistent with a yardstick regulation regime. We would moreover offer the suggestion, that this better alignment of regulated prices with the principles of yardstick regulation is likely to have contributed significantly to both the catch-up in quality adjusted productivity illustrated in Figure 5.

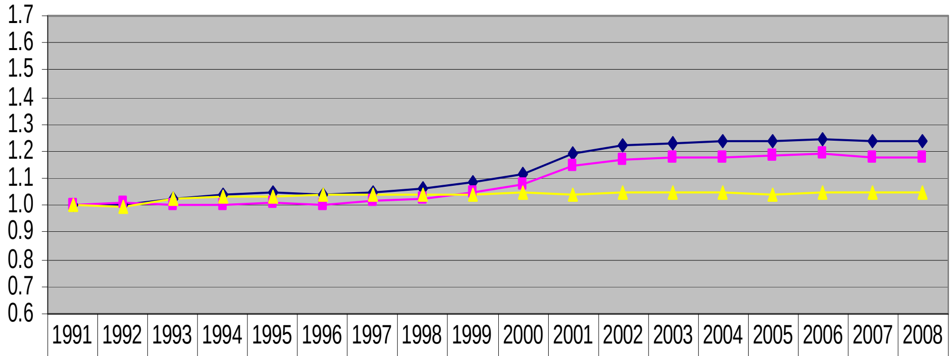
Further, considering the post 2001 period, reveals a steady downward trend in quality adjusted average and benchmark TPP except for the years 2002 and 2006. This overall finding supports a steady deterioration in price performance, which suggests that in practice, price caps have become even tighter since 2001. While , the catch up index reached a low of 0.843 in 2003 and has moderately increased to 0.877 in 2008, its trend in the post 2001 period largely suggests that the relatively superior price performance of the benchmark firm was maintained in the 2004 price review. Our results therefore suggest that when quality is taken into account in TPP measures, the broad convergence after 2000 between average and benchmark firm price performance which was observed in the quality unadjusted TPP results in Figure 6.6 is no longer present. Stated differently, when quality is taken into account, an average firm saw its price performance decline relative to the benchmark by 12.3% between 1991 and 2008 as benchmark quality adjusted benchmark TPP declined by only 20.4% while average TPP showed a higher reduction of 31.2%.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Unit-Specific	1.000	1.090	1.134	1.156	1.109	1.045	1.052	1.008	1.007	1.058	0.780	0.821	0.760	0.729	0.706	0.750	0.709	0.698
Catch-Up	1.000	1.056	1.028	1.036	0.990	0.958	0.936	0.967	0.981	0.942	0.878	0.858	0.843	0.844	0.852	0.851	0.852	0.877
Best	1.000	1.032	1.103	1.116	1.121	1.091	1.124	1.043	1.027	1.123	0.889	0.956	0.902	0.863	0.828	0.882	0.832	0.796

Figure 6 Decomposition of Average Unit-Specific Quality Adjusted TPP Change into Benchmark TPP Change and Average Catch-Up to the Benchmark Firm

Finally, Figure 7 shows the decomposition of average unit-specific quality change into average quality catch-up relative to the benchmark firm and the quality change of the benchmark firm, as illustrated in the third line of equation (8’). Until 1997, there were small or no gains in average quality relative to benchmark quality but after 1998 and most of the period of study average quality growth significantly exceeded benchmark quality growth, with particularly high levels of quality catch-up during between 1998 and 2002. By 2005, average quality improved by 23.5% while benchmark quality increased by 4.1% allowing average quality to catch-up to the benchmark by 18.6%. After 2005, average quality continue to increase at a lower rate, however, it showed a significant decline in 2007 and in 2008 which affected the quality adjusted TFP growth rates, whereas benchmark quality followed a stable slow upward trend. We need to emphasize that the small quality growth of the benchmark firm did not imply that the benchmark did not achieve significant quality levels. In contrast, our results suggest that at privatization the quality standards of the benchmark firm had already been at a high level and by 2005 on average the less productive firms had significantly improved their quality relative to the benchmark and had finally reached the higher levels of quality of the benchmark firm. Given the considerable cost of these quality improvements, figure 7 illustrates the importance of controlling for quality changes if we wish to properly gauge relative productivity, price, profitability, and catch up performance.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Unit-Specific	1.000	1.006	1.025	1.037	1.045	1.044	1.051	1.063	1.084	1.120	1.191	1.220	1.231	1.234	1.235	1.243	1.236	1.234
Catch-Up	1.000	1.011	1.003	1.005	1.012	1.004	1.017	1.026	1.047	1.076	1.143	1.167	1.177	1.178	1.186	1.190	1.178	1.177
Best	1.000	0.995	1.021	1.031	1.033	1.040	1.039	1.043	1.042	1.046	1.042	1.045	1.045	1.048	1.041	1.044	1.049	1.048

Figure 7 Decomposition of Average Unit-Specific Quality Change into Average Quality Change Catch-Up and Benchmark Quality Change

6. Summary and Conclusions

This paper analyzed the impact of regulation on the financial performance of WaSCs in England and Wales over the period 1991-2008. We linked together the spatial and temporal indices in order to derive estimates of relative productivity, price performance and profitability measures over time. Since substantial improvements in quality have affected the productivity and price performance of the water industry, unit-specific profitability change was also expressed as a function of the unit-specific quality adjusted productivity and quality-adjusted price performance change. This was further decomposed as a function of the quality adjusted catch-up in productivity, and the quality adjusted productivity growth of the benchmark firm, and the quality adjusted catch-up in price performance, and the quality adjusted price performance growth of the benchmark firm. The inclusion of quality in our analysis allowed us to eventually decompose unit-specific economic profitability change as a function of the quality unadjusted catch-up in productivity, the catch-up in quality, and the quality-unadjusted productivity and quality performance over time of the benchmark firm, and the quality unadjusted catch-up in price performance, the catch-up in quality regarding price performance, and the price performance and quality growth of the benchmark firm, in a binary and multilateral context.

The results indicated that while quality improvements have contributed to the productivity performance of the WaSCs, they have also contributed negatively to their price performance. The quality adjusted TFP results indicated that although average productivity slightly exceeded benchmark productivity until 1995, the rate of quality adjusted productivity growth for the average and benchmark firms was significantly greater than the quality unadjusted TFP indicating that quality improvements did lead to higher productivity growths. After 1997 and until 2002, average quality adjusted TFP increased more rapidly than benchmark quality adjusted TFP, therefore allowing average company to catch-up to benchmark quality adjusted productivity. Even after 2002 the average company achieved still significant levels of catch-up in quality adjusted productivity until 2005, which must be attributed to input usage reductions. Nevertheless, after 2005, when the relatively looser 2004 price review came into effect, high levels of productivity catch-up were no longer indicative of general productivity improvements, as average quality adjusted productivity levels were largely static after 2005. Instead, they reflected a substantial decline in the benchmark firm's productivity after 2006. Thus, our results may be interpreted as suggesting that after the 2004 price review, substantial productivity improvements were no longer occurring.

Furthermore, focusing on the results for the average and benchmark quality growth, it is concluded that until 1997 there were small gains in average quality relative to benchmark quality but after 1998 average quality substantially exceeded benchmark quality showing high levels of catch-up during the years 2000-2005. By 2005 the less productive firms on average improved significantly their quality relative to the benchmark which already had high levels of quality since privatization.

Moreover, the quality adjusted TPP results suggested that until 1994, average TPP exceeded benchmark TPP but after 1998, there was a steady erosion of average price performance relative to benchmark price performance suggesting that there was a considerable rebalancing of regulatory price decisions in favour of the benchmark firm, which was even more dramatically extended with the implementation of the 1999 price review in 2001. The dramatic fall in both average and benchmark quality adjusted TPP suggested that that both the 1994 and 1999 price reviews resulted in considerable movement to a regulatory price cap system consistent with a yardstick regulation regime. We would moreover offer the suggestion that this better alignment of regulated prices with the principles of yardstick regulation is likely to have contributed significantly to both the catch-up in quality adjusted productivity and the catch up in economic profitability. Further, considering the post 2001 period revealed a steady downward trend in quality adjusted average and benchmark TPP except for the years 2002 and 2006. This overall finding supported a steady deterioration in price performance, which suggested that in practice, price caps have become even tighter since 2001. Also after 2001 average quality adjusted TPP fell more than benchmark quality adjusted TPP suggesting that the broad convergence after 2000 between average and benchmark firm price performance which was observed in the quality unadjusted TPP results was no longer present.

Overall, our index number based approach provided a backward-looking approach regarding the impact of price cap regulation on the profitability, productivity and price performance of less productive and benchmark firms even if the number of available observations was extremely limited. We strongly believe that our methodology can be of great aid for regulators in setting X-factors under price cap regulation for regulated firms (forward-looking). Since X-factor requires the measurement of efficiency change (catch-up) and frontier shift (technical change), our approach provides evidence for catch-up (efficiency) in productivity by less productive firms based on the consistent spatial productivity measures across companies at any given year and also provides evidence for the productivity growth of the benchmark firm (technical change).

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