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Keywords: X-factor, Productivity Decomposition, Panel Index Numbers, Regulation, Water and Sewerage Industry

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A METHODOLOGY TO PROPOSE THE X-FACTOR IN THE REGULATED ENGLISH AND WELSH WATER AND SEWERAGE COMPANIES

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Abstract

The purpose of this paper is to develop a methodology which can be used to set X-factor under price cap schemes, when the number of observations is limited. We firstly apply a panel index approach across Water and Sewerage companies (WaSCs) over time to decompose unit-specific index number based productivity growth as a function of the productivity growth achieved by benchmark firms, and the catch-up to the benchmark firm achieved by less productive firms. We then calculate the potential productivity catch-up of laggard firms and an estimate of how the top performing company improved its productivity over time (technical change). Both estimates are used to propose X-factor for the industry over a particular period. The results indicated that significant gains in productivity occurred after 2000, when Ofwat set tighter price cap reviews in order to pass previous productivity benefits to consumers. However, average WaSC still needs to improve its productivity towards the benchmark firm (reduce their costs in real terms) by 2.69%, while the most productive firm needs to continue to improve its productivity by 0.95% over a period of five years. This technique is of great interest to researchers who are interested in developing comparative performance measurement under regulation and setting appropriate regulated prices when sample sizes are 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.

The method of regulation in the UK water and sewerage sector is price cap regulation and is designed to both give firms incentives to increase profits by reducing costs and eliminating the potential to manipulate output prices. The price cap scheme has the form of $RPI \pm K$, where RPI is the retail price index and K includes two components; X which reflects the beliefs of the regulator about potential improvements in productivity (reduction in costs) that the regulated companies can achieve over a specific period and Q, which reflects the allowed capital expenditure for mandated quality investment projects to improve water and sewerage quality and environmental standards.

At privatization in 1989, price limits were set by the Secretary of State for a period of ten years and were, on average, RPI +5.2 per annum for the industry, RPI+5 per annum for WaSCs and RPI+6.1 per annum for WoCs. The K factor was set at a high level in order to make up for years of underinvestment before privatization and to ensure that the shares of the public

[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.

companies would be attractive to potential investors. However, as documented in past studies (Saal and Parker, 2001) the first price caps were relatively lax allowing the firms to gain extraordinary profits, and as a result Ofwat exercised its right to reset price caps in 1994. Thus, the average K factor after the 1994 reviews was RPI+0.9 for the industry, RPI+1.0 for the WaSCs and RPI-0.4 for the WoCs, representing a considerable tightening of price caps. This continued in the price review of 1999 with an average K factor of RPI-2.1 for the industry, RPI-2.0 for the WaSCs and RPI-2.8 for the WoCs. In the price review of 2004 the K factor increased again to an average of 4.2% per annum, whereas in 2009 Ofwat published its final price determinations suggesting an average K factor of RPI+0.5 per annum for WaSCs ,and RPI+0.3 per annum for WoCs for the next five years. The setting of X-factors includes the measurement of industry-level annual productivity growth using historic data and firm-level relative efficiency using average-based and frontier-based methods (benchmark techniques). As there are companies that are regulated under the same framework, the regulator can compare the performance of each company against the performance of the others in the industry. Ofwat had developed econometric and unit cost analysis techniques to measure the relative efficiency of WaSCs and WoCs after taking into account factors that are outside a company's control and may influence differences between companies' costs.

Empirical modelling techniques such as stochastic frontier or econometric analysis (Lynk, 1993, Saal and Parker, 2000 and 2006), regression analysis (Ashton, 2000a), data envelopment analysis (Portela et al, 2009, Thanassoulis, 2000a and 2002) or index numbers (Saal and Parker, 2001, Maziotis, Saal and Thanassoulis, 2009 and 2012) were used to assess comparative efficiency and productivity measurement. However, none of the above studies extended their methodologies for setting X-factor for the UK water and sewerage regulated companies. In contrast, studies have appeared in the recent years that used data envelopment analysis (Coelli and Walding, 2006) or index number techniques (Lawrence and Diewert, 2006, Bernstein et al, 2006) to measure productivity growth and propose X-factors in regulated industries such as the water supply industry in Australia, the electricity network in New Zealand and telecommunication industry in Peru.

The purpose of this study is to allow the decomposition of unit specific index based number productivity growth in order to account for the contribution of both productivity growth achieved by benchmark firms, as well as the contribution of productivity catch-up by less productive firms. This is accomplished by following the methodology previously developed by Maziotis, Saal and Thanassoulis (2012) which extends the approach of Saal and Parker (2001) and Maziotis, Saal and Thanassoulis (2009). Thus, efficiency X-factors for the water and sewerage companies in England and Wales can be proposed. Firstly, we provide measures of temporal (unit-specific) productivity across time for each firm. Secondly, we allow productivity comparisons across companies at any given year (multilateral spatial comparisons) calculated by using a multilateral Fisher index. Thirdly, by reconciling together the temporal and spatial productivity measures into relative productivity measures, we provide a single index that consistently measures productivity performance change between both firms and over time. Finally, the reconciliation of the spatial, temporal and relative productivity measures allows us to decompose the unit-specific index based number productivity growth as a function of the productivity growth achieved by benchmark firms, and the catch-up to the benchmark firm achieved by less productive firms.

Moreover, since the UK water and sewerage industry is characterized by high capital investment programs to improve drinking water quality and environmental standards and past research has demonstrated that quality improvements do significantly impact temporal and spatial productivity measures (see Saal & Parker, 2001, Maziotis, Saal and Thanassoulis, 2009), we therefore test the impact of quality on our productivity measures. The quality adjusted unit specific productivity growth is decomposed into two additional factors, quality catch-up by less productive firms and quality growth achieved by the benchmark firm. Finally, based on the spatial productivity results in the latest year in our sample and the relative productivity change measures, we calculate the potential (anticipated) productivity catch-up of laggard firms and an estimate of how the top performing company improved its productivity over time (frontier shift), which is then used to propose X-factors for the water and sewerage sector over a particular period (five years). We illustrate our analytical decomposition of productivity change with an empirical application to the regulated English and Welsh water and sewerage industry during the period 1991-2008.

The paper unfolds as follows. Section 2 discusses the potential application of index number techniques for measuring productivity performance in a binary context. Section 3, then considers the methodology necessary to empirically apply this approach in a multilateral setting. The following section provides a discussion of data employed and the next section details the empirical results. Section 6 finally concludes.

2. Relative Productivity Performance: A Theoretical Illustration With Bilateral Indices

In this section we first illustrate unit specific, spatial and relative indices of productivity and their decomposition. We also employ these indices to illustrate how firm specific productivity change can be decomposed as a function of the productivity growth of a base firm and productivity catch-up relative to that firm over time.

2.1 Unit Specific Productivity Performance Indices

We first define the unit specific decomposition of productivity following the approach of Saal & Parker (2001) and originally illustrated in Waters & Tretheway (1999). This approach measures productivity performance between two time periods, year t and base year l for firm i. It therefore only measures differences in the temporal dimension for the given firm.

We can thus define and decompose a unit-specific (temporal) index of productivity for firm i at period t relative to the base period l, $TFP_{i,t}^{US}$, as follows:

$$TFP_{i,t}^{US} = \frac{\dfrac{Y_{i,t}}{X_{i,t}}}{\dfrac{Y_{i,l}}{X_{i,l}}} = \frac{\dfrac{Y_{i,t}}{Y_{i,l}}}{\dfrac{X_{i,t}}{X_{i,l}}} = \frac{Y_{i,t}^{US}}{X_{i,t}^{US}} \qquad (1)$$

As $TFP_{i,t}^{US} = Y_{i,t}^{US} / X_{i,t}^{US}$ this index can be further decomposed as functions of the unit-specific output ($Y_{i,t}^{US} = Y_{i,t} / Y_{i,l}$) and input ($X_{i,t}^{US} = X_{i,t} / X_{i,l}$) indices, where $Y_{i,t}$ and $Y_{i,l}$ denote the aggregate output indices at period t and the base period l and $X_{i,t}$ and $X_{i,l}$ denote the aggregate input indices at period t and the base period l, respectively.

2.2 Spatial Productivity Performance Indices

We next consider the productivity 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, this index only directly measure differences in productivity in the spatial dimension (between firms) at any given time. We can thus define and decompose a spatial productivity index for any firm i relative to the base firm b at period t, $TFP_{b,t}^{S}$ as follows:

$$TFP_{i,t}^{S} = \frac{\dfrac{Y_{i,t}}{X_{i,t}}}{\dfrac{Y_{b,t}}{X_{b,t}}} = \frac{\dfrac{Y_{i,t}}{Y_{b,t}}}{\dfrac{X_{i,t}}{X_{b,t}}} = \frac{Y_{i,t}^{S}}{X_{i,t}^{S}} \qquad (2)$$

As $TFP_{i,t}^{S} = Y_{i,t}^{S} / X_{i,t}^{S}$ this index can be further decomposed as functions of the spatial output ($Y_{i,t}^{S} = Y_{i,t} / Y_{b,t}$) and input ($X_{i,t}^{S} = X_{i,t} / X_{b,t}$) indices, where $Y_{b,t}$ and $X_{b,t}$ denote the aggregate output and input indices of the base firm b at period t, respectively.

By definition spatial indices estimate firm *i*'s performance relative to any potential base firm *b*, and therefore should have potential applications in regulatory settings on this basis alone. Spatial performance indices can also be employed to measure catch up in relative performance. Thus, if we have access to data for the base year *l* and any other year t, we can define and decompose an index of productivity catch up for any firm i at time t relative to the base firm b at time t, $TFP_{i,t}^{C}$, as follows:

$$TFP_{i,t}^{C} = \frac{TFP_{i,t}^{S}}{TFP_{i,l}^{S}} = \frac{\dfrac{Y_{i,t}^{S}}{Y_{i,l}^{S}}}{\dfrac{X_{i,t}^{S}}{X_{i,l}^{S}}} = \frac{Y_{i,t}^{C}}{X_{i,t}^{C}} \qquad (3)$$

Thus, for firm i at time t, an index of productivity catch up, $TFP_{i,t}^{C}$ can be expressed as a function of an index of spatial total factor productivity for firm i relative to the base firm *b* from different time periods l and t, $\frac{TFP_{i,t}^{S}}{TFP_{i,l}^{S}}$. As $TFP_{i,t}^{C} = Y_{i,t}^{C} \big/ X_{i,t}^{C}$ this index can be further decomposed as a function of catch up indices for outputs ($Y_{i,t}^{C} = Y_{i,t}^{S} \big/ Y_{i,l}^{S}$) and inputs ($X_{i,t}^{C} = X_{i,t}^{S} \big/ X_{i,l}^{S}$).

2.3 Relative Productivity Performance Indices

We finally define the productivity performance for any firm i at any time t relative to a base firm b at the base time l. As by construction this index is measured relative to a constant base for all t and all i, it therefore captures differences in both the spatial and the temporal dimensions for any given firm at any given time. We can thus define and decompose a relative index of productivity change at time t for firm i relative to the base firm b at base year l, $TFP_{i,t}^{P}$, as follows:

$$TFP_{i,t}^{R} = \frac{\dfrac{Y_{i,t}}{X_{i,t}}}{\dfrac{Y_{b,l}}{X_{b,l}}} = \frac{\dfrac{Y_{i,t}}{Y_{b,l}}}{\dfrac{X_{i,t}}{X_{b,l}}} = \frac{Y_{i,t}^{R}}{X_{i,t}^{R}} \tag{4}$$

Thus, for firm *i* at time t, the relative productivity index, $TFP_{i,t}^{R}$ can be expressed as a ratio of an index of total factor productivity for any firm *i* relative to the base firm *b* at base year *l* at any time t, $\frac{TFP_{i,t}}{TFP_{b,l}}$. As $TFP_{i,t}^{R} = Y_{i,t}^{R} \big/ X_{i,t}^{R}$ this index can be further decomposed as functions of the relative output ($Y_{i,t}^{R} = Y_{i,t} \big/ Y_{b,l}$) and input ($X_{i,t}^{R} = X_{i,t} \big/ X_{b,l}$) indices where $Y_{b,l}$ and $X_{b,l}$ denote the aggregate output and input indices of the base firm b at year *l*, respectively.

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

$$TFP_{i,t}^{US} = \frac{\dfrac{Y_{i,t}^{R}}{Y_{i,l}^{R}}}{\dfrac{X_{i,t}^{R}}{X_{i,l}^{R}}} = \frac{TFP_{i,t}^{R}}{TFP_{i,l}^{R}} \tag{5}$$

Similarly, as $TFP_{i,t}^{S} = TFP_{i,t}^{R} \big/ TFP_{b,t}^{R}$, $Y_{i,t}^{S} = Y_{i,t}^{R} \big/ Y_{b,t}^{R}$, $X_{i,t}^{S} = X_{i,t}^{R} \big/ X_{b,t}^{R}$:

$$TFP_{i,t}^{S} = \frac{\dfrac{Y_{i,t}^{R}}{Y_{b,t}^{R}}}{\dfrac{X_{i,t}^{R}}{X_{b,t}^{R}}} = \frac{TFP_{i,t}^{R}}{TFP_{b,t}^{R}} \tag{6}$$

Estimates of $TFP_{i,t}^{C}$ can then be constructed with the underlying relative productivity indices, and can in fact be constructed as the ratio of either firm 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 firm specific productivity growth indices.

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

Rearranging, (7) and decomposing the productivity index we can write:

$$TFP_{i,t}^{US} = TFP_{i,t}^{C} \times TFP_{b,t}^{US} \tag{8}$$

Thus, given the availability of relative performance indices, the temporal productivity of a firm i over time, $TFP_{i,t}^{US}$ can be decomposed as a function of the productivity growth of the base firm b, $TFP_{b,t}^{US}$ and the productivity catch-up of the firm i relative to the base firm between time l and t, $TFP_{i,t}^{C}$, e.g. productivity performance of any firm can be decomposed into a measure capturing the productivity change of a reference firm, and the given firm's productivity change relative to that reference firm. If $TFP_{i,t}^{C} > 1$, then firm i improved its productivity relative to the base firm from time l to t, whereas a value lower than 1 indicates that relative productivity of firm i has declined relative to that of the base 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" firm. Our next section therefore discusses a methodological approach that allows the actual application of the bilateral concepts detail above in an empirical multilateral setting.

3. Productivity Computations In Practice

3.1. Chained Unit-specific Productivity Over Time

In this section we calculate chained unit-specific productivity growth following Saal and Parker's approach (2001). We thus measure these performance measures for any firm between two time periods by using a temporal Fisher index number approach. 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 $X_{i,t}$, :

$$Y_{i,t} = [\frac{\sum_{m=1}^{M} P_1^m Y_t^m}{\sum_{m=1}^{M} P_1^m Y_1^m} \times \frac{\sum_{m=1}^{M} P_t^m Y_t^m}{\sum_{m=1}^{M} P_t^m Y_1^m}]^{\frac{1}{2}} \qquad X_{i,t} = [\frac{\sum_{n=1}^{N} W_1^n X_t^n}{\sum_{n=1}^{N} W_1^n X_1^n} \times \frac{\sum_{n=1}^{N} W_t^n X_t^n}{\sum_{n=1}^{N} W_t^n X_1^n}]^{\frac{1}{2}} \tag{9}$$

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 then constructed as a ratio of Fisher output index relative to Fisher input index, which takes the value 1 in the year 1 (base period):

$$TFP_{i,t} = \frac{Y_{i,t}}{X_{i,t}} \tag{10}$$

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:

$$Y_{i,t}^{CH} = 1 \times Y_{i,1,2} \times Y_{i,2,3} \times ... \times Y_{i,t-1,t} \qquad X_{i,t}^{CH} = 1 \times X_{i,1,2} \times X_{i,2,3} \times ... \times X_{i,t-1,t} \tag{11}$$

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 $X_{i,t}^{CH}$:

$$TFP_{i,t}^{CH} = \frac{Y_{i,t}^{CH}}{X_{i,t}^{CH}} \tag{12}$$

3.2. Spatial Productivity Computations

In the previous section, we used a chained Fisher index to measure productivity performance of any firm between period 1 and period t. In this section, we derive a spatial (bilateral) Fisher index to measure productivity performance across companies at any given year (spatial comparisons). Spatial Fisher output and input indexes between two firms i and j in the case of m outputs and n inputs are respectively, $Y_{i,j}^{S}$ and $X_{i,j}^{S}$:

$$Y_{i,j}^{S} = [\frac{\sum_{m=1}^{M} P_j^m Y_i^m}{\sum_{m=1}^{M} P_j^m Y_j^m} \times \frac{\sum_{m=1}^{M} P_i^m Y_i^m}{\sum_{m=1}^{M} P_i^m Y_j^m}]^{\frac{1}{2}} \qquad X_{i,j}^{S} = [\frac{\sum_{n=1}^{N} W_j^n X_i^n}{\sum_{n=1}^{N} W_j^n X_j^n} \times \frac{\sum_{n=1}^{N} W_i^n X_i^n}{\sum_{n=1}^{N} W_i^n X_j^n}]^{\frac{1}{2}} \tag{13}$$

where Y_i^m and Y_j^m denote the quantities for the mth output for firms i and j respectively, whereas X_i^n and X_j^n present the quantities for the nth inputs for firms i and j respectively. Moreover, P_i^m and P_j^m are the prices for mth output, while W_i^n and W_j^n denote the input prices. The Fisher output and input indexes measure firm i's output and input as a proportion of firm j and are the geometric means of Laspeyers and Paasche output and input indexes. For instance, Laspeyers output and input indexes use company j 's prices to weight quantity changes, whereas Paasche output and input indexes use firm i's prices to weight quantity changes. The spatial Fisher productivity index is then constructed as a ratio of the Fisher output index relative to Fisher input index:

$$TFP_{i,j}^{S} = \frac{Y_{i,j}^{S}}{X_{i,j}^{S}} \tag{14}$$

The above formula is a binary comparison that can be applied directly when we are only interested in making comparisons between two firms. 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:

$$TFP_{i}^{S} = \frac{Y_{i}^{S}}{X_{i}^{S}} \tag{15}$$

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:

$$TFP_{i,t}^{S} = \frac{Y_{i,t}^{S}}{X_{i,t}^{S}} \tag{16}$$

3.3. Relative Productivity Change Over Time

In order to simultaneously measure and decompose the productivity growth of any firm in the sample across time and relative to other firms, in practice it is necessary to reconcile the spatial productivity measures defined above with the underlying unit-specific chained productivity of each firm. 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 yardstick 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. .

Given these arguments, we follow Hill's approach (2004) and 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:

$$TFP_{i,t}^{R} = \left[\prod_{j=1}^{I} \left[(TFP_{j,t}^{CH} \times TFP_{j,1}^{S}) \times \frac{TFP_{i,t}^{S}}{TFP_{j,t}^{S}} \right] \right]^{\frac{1}{I}} \tag{17}$$

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

[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.

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 (17) employs all available spatial and chained productivity estimates to provide an arguably superior geometric average estimate of $TFP_{i,t}^{R}$.

In order to achieve our ultimate goal of decomposing unit specific productivity growth, as demonstrated in (8) in the bilateral context, we must finally derive unit specific indices which are consistent with the relative indices developed in (17). 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 $Y_{i,t}^{US} = \frac{Y_{i,t}^{R}}{\mathrm{Y}_{\mathrm{i,1}}^{\mathrm{R}}}$ and $X_{i,t}^{US} = \frac{X_{i,t}^{R}}{\mathrm{X}_{\mathrm{i,1}}^{\mathrm{R}}}$.

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 equation (17) are equal. Thus, for example, if we take the geometric average across all firms *I* in the sample, then $\left[\prod_{i=1}^{I}\left(TFP_{i,t}^{CH}\right)\right]^{\frac{1}{I}} = \left[\prod_{i=1}^{I}\left(TFP_{i,t}^{US}\right)\right]^{\frac{1}{I}}$. 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.

3.4. Application

The importance of the derivation of productivity measures across firms and over time using index numbers is twofold. Firstly, as alternative methodologies, such as DEA and SFA, require a relatively large number of observations to specify an efficient frontier, our index number based approach has the further potential advantage of allowing meaningful comparative performance measurement even if the number of available observations is extremely limited. Secondly and more significantly, our methodology is particularly applicable to comparative performance measurement under regulation, where consideration of both temporal and spatial differences in TFP is necessary for setting appropriate regulated prices. The above spatial, unit-specific and relative productivity change measures over time provide information regarding the productivity gains achieved by less productive firms and the productivity growth achieved by the benchmark firm (backward-looking). However, the potential (anticipated) productivity catch-up of laggard firms and the estimate of how the top performing company improved its productivity over time (frontier shift) can be applied in setting the X-factors in regulated industries under price cap regulation (forward-looking).

If we identify as the base firm b the highest productivity firm, then each spatial productivity measure is a measure of firm i's productivity relative to the productivity of the best firm observed in the sample at any time t, $TFP_{i,t}^{S} = \frac{Y_{i,t}^{S}}{X_{i,t}^{S}}$ and consequently, the productivity catch-up of a firm i to the best firm, can be simply calculated as the ratio of relative productivity index of a firm i relative to the best practice firm b from different periods of time, l and t, $TFP_{i,t}^{C} = \frac{TFP_{i,t}^{S}}{TFP_{i,l}^{S}}$.

Also, based on spatial comparisons in a given year we can provide an estimate of the potential (anticipated) annual productivity improvements $\left(TFP_i^{PI}\right)$ of a firm i if it was required to catch-up to the best firm over a period of T years:

$$TFP_i^{PI} = \left(\frac{1}{TFP_i^S}\right)^{\frac{1}{T}} \tag{18}$$

Finally, the consistent rate of productivity growth of the best firm in the sample based on the relative productivity change measures, $TFP_{b,t}^{US}$, provides us with an estimate of how the top performing company improved its productivity over time (frontier shift).

This section has specified a methodology to allow the empirical application of unit-specific, spatial and relative productivity indices and their decomposition into unit-specific, spatial and relative productivity performance indices in a multilateral setting. We firstly, calculated chained productivity indices for each firm over time. Then, we derived spatial productivity indices across firms for each year. Then by reconciling together temporal chained and spatial indices, we were able to derive relative productivity comparisons across firms and over time that guarantee spatial consistency. 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 productivity performance change. Consequently, we are able to consistently decompose unit specific productivity change as a function of the productivity growth of a base firm and productivity catch-up relative to that firm over time, which can be further decomposed as a function of the productivity of a base firm and productivity catch-up relative to that firm over time. However, the potential (anticipated) productivity catch-up of laggard firms and the estimate of how the top performing company improved its productivity over time (frontier shift) can be applied in setting the X-factors in regulated industries under price cap regulation (forward-looking). In the discussion of the results we report X-factors for the water and sewerage companies based on the spatial measures of the latest period in our sample and the consistent measures of unit-specific productivity growth over time of the highest productivity firm. We need to emphasize that we apply the methodology described above for a total cost modeling to set X-factors for the UK water and sewerage industry. Till the 2004 price review Ofwat developed cross section econometrics and unit cost methods to setting X-factors separately for operating expenditure (OPEX) and capital expenditure (CAPEX) model. Our approach can also be employed by regulator and regulated companies when comparative performance and regulated prices are assessed and set separately for OPEX and CAPEX.

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.

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 measures, we are able to calculate indices of unit-specific, spatial and relative input usage discussed above

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), Maziotis, Saal and Thanassoulis (2009) demonstrated that quality improvements do significantly impact temporal and spatial productivity performance estimates. Thus, we feel it is important to measure the impact of quality in our unit-specific, spatial and relative productivity measures, thereby allowing for the cross sectional and intertemporal variation in the sewage and drinking water quality. We therefore calculated quality-adjusted measures of output for water and sewerage services, as the product of water output and a drinking water quality index and sewerage output and a sewage treatment quality index, respectively.

[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.

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 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

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[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.

[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.

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 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.[6]

Once the quality adjusted water and sewerage outputs are constructed, quality adjusted indices are straightforward to produce, by simply repeating the procedures identified above to first produce spatially consistent quality adjusted output indices ($Y_{i,t}^{S,Q}$). We can also derive a spatial implicit quality index ($Q_{i,t}^{S}$) which measures the implied difference in quality relative to

[6] To highlight this, we note that while our weighted index implies an increase in sewage treatment quality of 19.3% for all England and Wales between 1991 and 2008, an index based only on population receiving at least primary treatment would indicate a quality improvement of 13.7% while one based only on the percentage of population receiving at least secondary treatment of sewage would indicate a 25.4% quality improvement. However, our approach not only provides a mid range estimate between these two more extreme measures, but also better reflects the process of improving sewage treatment quality that occurred through both treating previously untreated sewage, and increasing the level of sewage treatment.

the base firm as $Q_{i,t}^{S} = Y_{i,t}^{S,Q} \big/ Y_{i,t}^{S}$. Therefore, quality adjusted spatial outputs and TFP can also be respectively expressed as $Y_{i,t}^{S,Q} = Q_{i,t}^{S} Y_{i,t}^{S}$ and $TFP_{i,t}^{S,Q} = Q_{i,t}^{S} TFP_{i,t}^{S}$. In an analogous manner, we can derive measures of relative quality adjusted output indices over time, $Y_{i,t}^{R,Q}$ and relative implicit quality index over time ($Q_{i,t}^{R}$) which measures the implied difference in quality over time relative to the base firm at the base period as $Q_{i,t}^{R} = Y_{i,t}^{R,Q} / Y_{i,t}^{R}$. Therefore, measures of quality adjusted relative outputs and TFP can also be respectively expressed as $Y_{i,t}^{R,Q} = Q_{i,t}^{R} Y_{i,t}^{R}$ and $TFP_{i,t}^{R,Q} = Q_{i,t}^{R} TFP_{i,t}^{R}$. Also, we can produce measures of unit-specific quality adjusted output indices over time, $Y_{i,t}^{US,Q}$ and implicit quality index over time ($Q_{i,t}^{US}$) which measures the implied difference in unit-specific quality over time as $Q_{i,t}^{US} = Y_{i,t}^{US,Q} / Y_{i,t}^{US}$. Therefore, estimates of temporal quality adjusted outputs and TFP over time can also be respectively expressed as $Y_{i,t}^{US,Q} = Q_{i,t}^{US} Y_{i,t}^{US}$ and $TFP_{i,t}^{US,Q} = Q_{i,t}^{US} TFP_{i,t}^{US}$

Therefore, by adjusting TFP measures for quality we are able to offer an alternative decomposition of unit-specific productivity growth, which, will more properly attribute quality improvements to productivity improvement and allows a further decomposition of equation (8) into the catch-up in quality regarding productivity achieved by less productivity firms and the quality growth in productivity 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, $Q_{i,t}^{C} = \dfrac{Q_{i,t}^{S}}{Q_{i,1}^{S}}$. Moreover, given the availability of $Q_{i,t}^{S}$, $Q_{i,t}^{US}$ and $Q_{i,t}^{P}$ the catch up in quality can be expressed in a similar manner to what was demonstrated in equation (7):

$$Q_{i,t}^{C} = \frac{Q_{i,t}^{S}}{Q_{i,1}^{S}} = \frac{\dfrac{Q_{i,t}^{R}}{Q_{b,t}^{R}}}{\dfrac{Q_{i,1}^{R}}{Q_{b,1}^{R}}} = \frac{\dfrac{Q_{i,t}^{R}}{Q_{i,1}^{R}}}{\dfrac{Q_{b,t}^{R}}{Q_{b,1}^{R}}} = \frac{Q_{i,t}^{US}}{Q_{b,t}^{US}} \tag{19}$$

Rearranging (19), 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 unit specific productivity change detailed in (8) can now be extended, in the multilateral context, as follows:

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

Thus, as in (8), in equation (8'), the quality adjusted unit-specific productivity change, $TFP_{i,t}^{US,Q}$ can be decomposed as a function of the quality unadjusted unit-specific productivity growth, $TFP_{i,t}^{US}$ and the unit-specific quality growth, $Q_{i,t}^{US}$. 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, $TFP_{b,t}^{US,Q}$. Finally, it 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 $Q_{b,t}^{US}$. If $TFP_{i,t}^{C} > 1$, then firm i improved its productivity relative to the base firm from year 1 to t, whereas a value lower than 1 indicates that productivity performance of firm i has declined relative to that of the base firm. If $Q_{i,t}^{C} > 1$, then the firm *i* improved its quality regarding productivity relative to the base firm from year 1 to year t, whereas a value lower than 1 indicates that relative quality regarding productivity of firm i has declined relative to that of the base firm.

5. Results From Productivity Computations

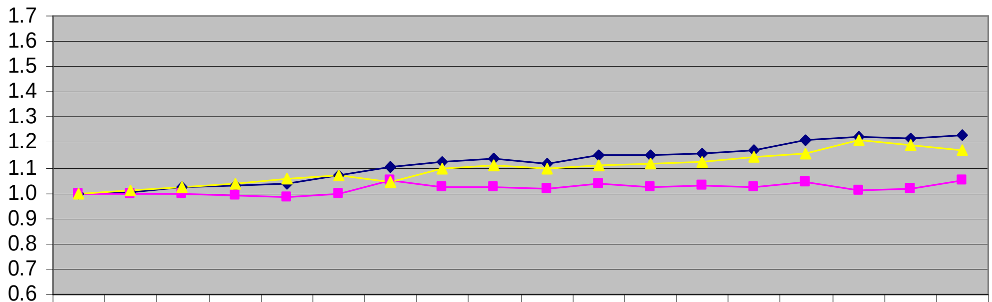
The above spatial and relative productivity measures were defined relative to the base firm in the sample. However, if the base firm is defined as the firm with the highest productivity in the sample, then each firm's productivity will be relative to this best practice or benchmark firm.[7] In this section we first report geometric average measures of unit-specific productivity in Figure 1. Subsequently, we demonstrate the further decomposition that is facilitated by our methodological approach by decomposing theses changes into an average catch-up component and the performance of the benchmark firm. Moreover, we first illustrate this for a quality unadjusted model in Figure 1, and then illustrate the impact of quality on these measures in Figures 2 to 5. Finally, we use Tables 1 and 2 to show how the spatial, unit-specific and relative productive measures can be used to set X-factors for the regulated Water and Sewerage Companies.

The decomposition of average unit-specific productivity growth into quality unadjusted productivity change of the benchmark firm and quality unadjusted average productivity catch-up relative to the benchmark firm is depicted in Figure 1. Till 1995 it is concluded that there was actually negative productivity catch-up as the productivity improvements for the average company amounted to 3.9%, while the benchmark company improved its productivity by 5.7%. This finding suggests that the lax price caps set at privatization did not encourage average or benchmark firms to achieve high productivity levels. However, this trend was interrupted after 1995 when both average and benchmark productivity performance significantly improved. During the years 1996-2000 when price caps were first tightened, average companies had stronger incentives to catch-up to benchmark, while the benchmark company was incentivized to continue to improve its productivity. By 2000, average cumulative productivity increased by 12% and this growth exceeded that of the benchmark firm, which achieved cumulative

[7] We have not identified firms for confidentially reasons. The same firm is consistently found to have the highest spatial productivity estimates for both quality unadjusted and quality adjusted models 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.

improvement of 9.8%, thereby indicating total catch-up in productivity of 2% between 1991 and 2000.

Moreover, significant productivity gains for the average firm relative to the benchmark firm also continued after 2000. Thus, our results suggest that the implementation of even tighter price caps in 1999 further encouraged less productive firms to improve their performance relative to the benchmark, even though the benchmark firm continued to improve its performance. Thus, by 2004, the cumulative measures of productivity change since 1991 indicate that average company improved its productivity by 16.8% catching up to the benchmark productivity by 2.3%, while the benchmark firm improved its productivity by 14.2%. During the last price review period, average productivity growth again substantially exceeded the productivity growth of the benchmark firm, resulting in high levels of productivity catch-up between 2005 and 2008, although this is largely explained by substantial declines in benchmark productivity after 2006. Overall, during the entire 1991-2008 regulatory period, average productivity improved by 22.9%, while benchmark productivity improved its productivity by 17% allowing an average productivity catch-up of 5%. Thus, all of this catch-up can be attributed to the post 1995 period, after Ofwat first tightened price caps, and most of it can be attributed to the post 2000 period, following the even more stringent 1999 price review.

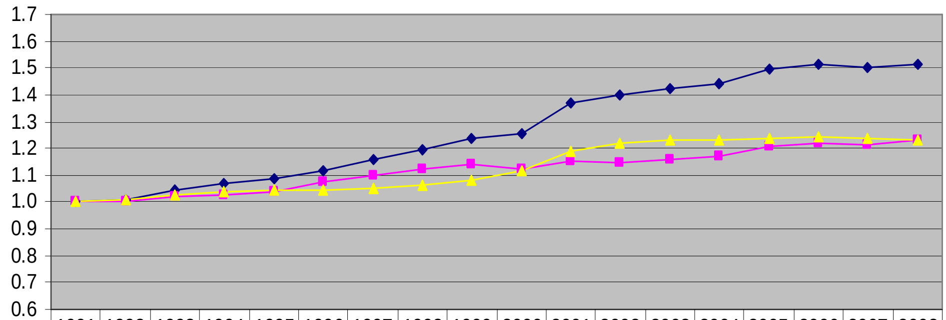


	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Unit-Specific	1.000	1.006	1.021	1.029	1.039	1.072	1.100	1.126	1.140	1.120	1.150	1.148	1.157	1.168	1.209	1.220	1.215	1.229
Catch-Up	1.000	0.995	0.997	0.990	0.982	1.000	1.052	1.026	1.025	1.020	1.034	1.027	1.029	1.023	1.042	1.010	1.021	1.050
Best	1.000	1.010	1.024	1.039	1.057	1.073	1.046	1.097	1.112	1.098	1.112	1.118	1.125	1.142	1.160	1.208	1.190	1.170

Figure 1 Decomposition of Average Unit-Specific Quality Unadjusted TFP Change into Benchmark TFP Change and Average Catch-Up to the Benchmark Firm

As discussed in section 4, the inclusion of quality in our productivity measures, allows us to decompose unit-specific productivity as a function of quality adjusted catch-up in TFP achieved by less productive firms relative to the benchmark firm and the quality adjusted TFP growth obtained by the benchmark firm. This decomposition illustrated at equation (8') and is visualised at Figures 2, 3 and 4.

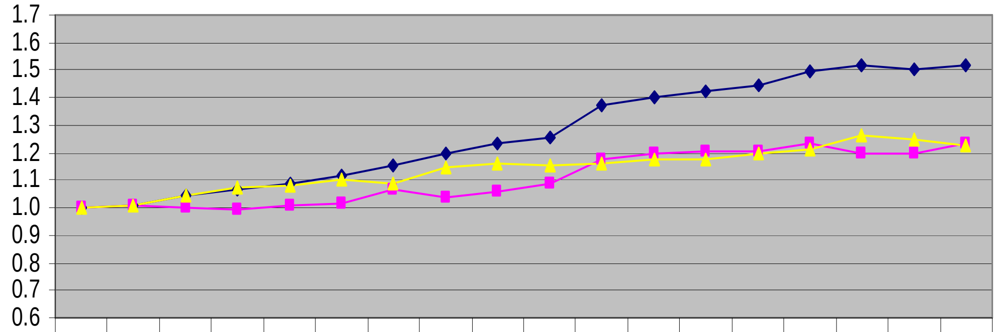
We begin with Figure 2 which depicts the decomposition of quality adjusted average TFP change into quality unadjusted average TFP change and quality change. High capital investment programs to improve quality conditions since privatization had a positive impact on quality adjusted output growth and consequently, 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 2 Decomposition of Average Unit Specific Quality Adjusted TFP Change into Average Unit-Specific TFP 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 3. 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%. 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.

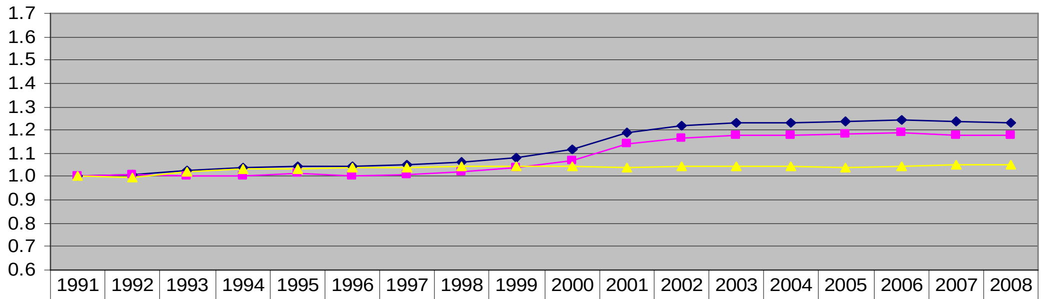


	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Unit-Specific	1.000	1.011	1.046	1.067	1.086	1.119	1.156	1.197	1.236	1.254	1.370	1.401	1.424	1.442	1.493	1.516	1.501	1.517
Catch-Up	1.000	1.006	1.000	0.996	1.007	1.013	1.063	1.041	1.061	1.088	1.179	1.195	1.208	1.202	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 3 Decomposition of Average Unit-Specific Quality Adjusted TFP Change into Benchmark TFP Change and Average Catch-Up to the Benchmark Firm

Finally, Figure 4 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 at 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 as we discussed in Figure 2, 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.



	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	1.011	1.020	1.040	1.070	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	1.047	1.042	1.045	1.046	1.048	1.042	1.044	1.049	1.048

Figure 4 Decomposition of Average Unit-Specific Quality Change into Average Quality Change Catch-Up and Benchmark Quality Change

Since we can compute the level of catch-up achieved by each company to the most productive firm and the productivity growth of the best firm based on our spatial and unit-specific productive measures over time (frontier shift), we can propose X-factors for the water and sewerage companies over a five year period. This is illustrated by the following example at Table 1, which depicts the quality-unadjusted spatial productivity results for WaSCs in 2008. Let's assume that we want to set an X-factor for Anglian using the results of its productivity relative to the most productive company in 2008, which is assumed to be the most productive firm in the sample. The potential (anticipated) productivity improvement of Anglian to catch-up to Severn Trent over time is 1/0.889=1.125 or 12.5%. Assuming that Anglian should achieve 50% catch-up for total costs over a 5-year period, then it should catch-up $[1+(1.125-1)/2]=1.062$ or 6.2% over a 5-year period. That means that Anglian should catch-up to the best firm $(1.062)^{\frac{1}{5}}=1.012$ or 1.2% per year. If we assume a $(1.170)^{\frac{1}{17}}=1.009=0.9\%$ continuing improvement factor based on the relative productivity change of Severn Trent over time, then the required productivity growth or the X-factor for Anglian can be $X=1.012\times1.009=1.021$ or 2.16% per year. In analogous manner, an X-factor for the average company could potentially be 2.64%.

Companies	Spatial TFP quality unadjusted (2008)	Potential productivity growth through catch-up	50% catch-up for total costs	Catch-up (%) per year	Continuing Improvement Factor	Required Productivity Growth	X-factor
Anglian	0.889	1.125	1.062	1.012	1.009	1.022	2.16%
Northumbrian	0.91	1.099	1.049	1.01	1.009	1.019	1.91%
United Utilities	0.707	1.414	1.207	1.038	1.009	1.048	4.80%
Southern	0.84	1.191	1.095	1.018	1.009	1.028	2.78%
Severn Trent	1	1	1	1	1.009	1.009	0.93%
South West	0.728	1.374	1.187	1.035	1.009	1.045	4.45%
Thames	0.893	1.12	1.06	1.012	1.009	1.021	2.12%
Welsh	0.741	1.35	1.175	1.033	1.009	1.042	4.23%
Wessex	0.769	1.3	1.15	1.028	1.009	1.038	3.79%
Yorkshire	0.89	1.123	1.062	1.012	1.009	1.021	2.15%
Average	0.832	1.202	1.103	1.02	1.009	1.029	2.64%

Table 1 - Setting X-factors Quality Unadjusted

In an analogous manner, after controlling for quality we can propose X-factors for WaSCs based on the quality adjusted spatial productivity measures and the unit-specific productivity growth of the best company. Thus, the quality adjusted potential (anticipated) productivity improvement of Anglian to catch-up to Severn Trent over time is 1/0.890=1.124 or 12.4%. Assuming that Anglian should achieve 50% catch-up for total costs over a 5-year period, then it should catch-up $[1+(1.124-1)/2]=1.062$ or 6.2% over a 5-year period. That means that Anglian should catch-up to the best firm $(1.062)^{\frac{1}{5}}=1.012$ or 1.2% per year. If we assume a $(1.1230)^{\frac{1}{17}}=1.012=1.2\%$ continuing improvement factor based on the quality adjusted relative productivity change of Severn Trent over time, then the required productivity growth or the X-factor for Anglian after taking into account quality in our analysis can be $X=1.012\times1.012=1.024$ or 2.43% per year. Finally, we can conclude that a quality-adjusted X-factor for the average company could potentially be 3.26%.

Companies	Spatial TFP quality adjusted (2008)	Potential productivity growth through catch-up	50% catch -up for total costs	Catch-up (%) per year	Continuing Improvement Factor	Required Productivity Growth	X-factor
Anglian	0.890	1.124	1.062	1.012	1.012	1.024	2.43%
Northumbrian	0.881	1.134	1.067	1.013	1.012	1.025	2.53%
United Utilities	0.693	1.442	1.221	1.041	1.012	1.053	5.33%
Southern	0.777	1.287	1.144	1.027	1.012	1.040	3.96%
Severn Trent	1.000	1.000	1.000	1.000	1.012	1.012	1.21%
South West	0.683	1.464	1.232	1.043	1.012	1.055	5.52%
Thames	0.878	1.139	1.069	1.014	1.012	1.026	2.58%
Welsh	0.731	1.368	1.184	1.034	1.012	1.047	4.69%
Wessex	0.745	1.342	1.171	1.032	1.012	1.045	4.46%
Yorkshire	0.854	1.171	1.085	1.017	1.012	1.029	2.88%
Average	0.807	1.238	1.121	1.023	1.012	1.036	3.26%

6. Conclusions

The purpose of this paper was to propose a methodology to propose X-factors for the UK water and sewerage companies when the number of observations is limited. In order to achieve this we first decompose unit specific productivity growth as a function of the productivity growth achieved by benchmark firms and the productivity catch-up by less productive firms. Based on this decomposition X-factors for the UK water and sewerage industry are proposed. We firstly specified a methodology to allow the empirical application of unit-specific, spatial and relative productivity indices and their decomposition into unit-specific, spatial and relative productivity performance indices in a multilateral setting, by firstly calculating chained productivity indices for each firm over time. Then, we derived spatial productivity indices across firms for each year and by reconciling together temporal chained and spatial indices, we were able to derive relative productivity comparisons across firms and over time that guarantee spatial consistency. By including also quality in our productivity measures, the quality adjusted unit specific productivity growth was further decomposed into two additional factors, the quality catch-up by less productive firms and the quality growth achieved by the benchmark firm. Finally, the potential (anticipated) productivity catch-up of laggard firms and the consistent measure of how the top performing company improved its productivity over time (frontier shift) were further applied for setting X-factors in water and sewerage companies (forward-looking).

The results indicated that by 2002 quality improvements have contributed to the productivity performance of the WaSCs. 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 higher than the quality unadjusted TFP indicating that quality improvements did lead to higher productivity growths. During the years 1997-2002, 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, based on the quality unadjusted and quality adjusted spatial and relative productivity change measures we were able to propose the X-factors for WaSCs over a five year period. The quality unadjusted results implies that on average the water and sewerage companies need to improve their productivity towards the benchmark firm (reduce their costs in real terms) by 2.64% over a period of five years. The most productive firm needs to continue improving its productivity by 0.93% over time (technical change), whereas the worst productive firm needs to catch-up by 4.80% to the frontier firm over a period of five years. Finally, the quality adjusted results indicate that on average the water and sewerage companies need to improve their productivity towards the benchmark firm by 3.26% over a five year period. The most productive firm needs to continue improve its productivity by 1.21% over time (technical change), whereas the worst productive firm needs to catch-up by 5.52% to the benchmark firm over a five year period.

The importance of our methodology is twofold. Firstly, as alternative methodologies, such as DEA and SFA, require a relatively large number of observations to specify an efficient frontier, our index number based approach has the further potential advantage of allowing meaningful comparative performance measurement even if the number of available observations is extremely limited. Secondly and more significantly, our methodology is particularly applicable to comparative performance measurement under regulation, where consideration of both temporal and spatial differences in TFP is necessary for setting appropriate regulated prices. The spatial, unit-specific and relative productivity change measures over time provide information regarding the productivity gains achieved by less productive firms and the productivity growth achieved by the benchmark firm (backward-looking). More importantly, the potential (anticipated) productivity catch-up of laggard firms and the estimate of how the top performing company improved its productivity over time (technical change) can be applied in setting the X-factors in regulated industries under price cap regulation (forward-looking). For the purposes of this study, we derived productivity measures across firms and over time based on a total economic cost model, however, our panel index methodology can be applied separately for only operating expenditure (OPEX) and only capital expenditure (CAPEX) models (e.g. Ofwat till the 2004 price review developed several models on assessing OPEX and CAPEX comparative efficiency analysis in the water and sewerage industry in England and Wales).

Taken as a whole, we strongly believe that our approach should be of great interest to researchers who are interested in developing comparative performance measurement under regulation when sample sizes are extremely limited, where consideration of both temporal and spatial differences in TFP is important for setting appropriate regulated prices. We therefore underline that our panel index methodology could further be applied by regulators to determine appropriate X-factors for regulated firms, as it not only provides evidence for potential productivity catch-up, but also provides evidence for further potential productivity improvements by benchmark firms (forward-looking).

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