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**Profit, Productivity and Price  
Performance Changes in  
The English and Welsh  
Water and Sewerage**

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### Summary

The purpose of this paper is to assess the impact of regulation in the financial performance of the Water and Sewerage companies (WaSCs) in England and Wales. We apply 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. The results indicated that the steady decline in average price performance, gains in productivity and relatively stable economic profitability after 2000, suggest that Ofwat is now more focused on passing productivity benefits to consumers, and maintaining stable profitability than it was in earlier regulatory periods. This technique is of great interest for regulators to evaluate the effectiveness of regulation and companies to identify the determinants of profit change and improve future performance, even if sample sizes are limited.

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

**JEL Classification:** Q5

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

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## **Abstract**

The purpose of this paper is to assess the impact of regulation in the financial performance of the Water and Sewerage companies (WaSCs) in England and Wales. We apply 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. The results indicated that the steady decline in average price performance, gains in productivity and relatively stable economic profitability after 2000, suggest that Ofwat is now more focused on passing productivity benefits to consumers, and maintaining stable profitability than it was in earlier regulatory periods. This technique is of great interest for regulators to evaluate the effectiveness of regulation and companies to identify the determinants of profit change and improve future performance, even if sample sizes are limited.

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

## 1. Introduction<sup>1</sup>

A firm's economic performance is commonly measured by its economic profitability ( $\pi$ ). However, changes in profitability can be decomposed into changes in productivity and price performance. Total factor productivity (TFP) captures changes in performance attributable to increased physical production of outputs relative to inputs. In contrast, total price performance (TPP) captures the impact of changes in output prices relative to input prices. Comparing changes in TFP and TPP therefore allows determination of whether profit change is primarily explained by improvements in productivity or is simply attributable to an increase in output prices relative to input prices that has improved the firm's price mark up relative to actual costs.

Maziotis, Saal and Thanassoulis (2009) developed a cross sectional (spatial) index number technique to allow for the measurement of productivity, regulatory price performance, and profitability across firms at any given time and showed the subsequent comparison of how these cross sectional measures have changed over time. The authors concluded that during the years 1991-2000 price caps were "weak" as prices were high enough for the firms to achieve economic profits despite their low productivity levels. However, after 2001 prices became "catch up promoting" as they required less productive companies to eliminate at least some excess costs in order to eliminate economic losses. Furthermore, another paper by Fox et al (2003) provided alternative index number profit decomposition by taking into account the impact of fixed input. The performance of all firms was compared to the most profitable firm. However, both papers did not measure how the performance of less profitable/productive firms towards the best practice firm changed over time (catch-up) and changes in the performance of best practice firm over time (frontier shift). Catch-up and frontier shift measures are of great significance in regulatory analysis.

Therefore, in this paper, we measure economic profitability and decompose it into total factor productivity (TFP) and total price performance (TPP), thereby extending a methodological framework originally suggested by Hill (2004) to allow

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for price indexes that span both multiple firms at a given time (multilateral spatial indexes) and a single firm over multiple periods (temporal indexes). This methodology overcomes the fact that multilateral spatial indexes, which allow consistent comparisons across multiple firms at any given time, are not necessarily consistent with temporal unit-specific indexes, which allow consistent comparison of a given firm across times. Our reconciliation of separate spatial and unit-specific profitability, TFP, and TPP indexes into a single index spanning both firms and time has a significant benefit in application. This is because it allows not only for indexes of unit-specific profitability, TFP, and TPP change, as in Saal & Parker (2001), Water and Street (1998), Han and Hughes (1999) and Salerian (2003), but also allows spatially consistent measurement of changes in these performance measures relative to other firms.

Our methodology is therefore particularly applicable to comparative performance measurement under regulation, where consideration of both temporal and spatial differences in profitability, TFP, and TPP are necessary for setting appropriate regulated prices. Moreover, 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.

As we demonstrate below, our analysis illustrates several theoretically related methods to measure and decompose financial performance across companies and over time. Firstly, we provide measures of temporal (unit-specific) profitability, productivity and price performance across time for each firm. Secondly, we allow profitability, productivity and price performance 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 profitability, productivity and price performance into relative profitability, productivity and price performance measures, we provide a single index that consistently measures performance change between both firms and over time. Finally, the reconciliation of the spatial, temporal and relative profitability, productivity and price performance measures allows us to decompose the unit-specific index based number profitability growth as a function of the profitability, productivity, price performance growth

achieved by benchmark firms, and the catch-up to the benchmark firm achieved by less productive firms. This not only extends the approach of Saal & Parker (2001), Water and Street (1998), Han and Hughes (1999), Salerian (2003) and Fox et al (2003) by allowing a more comprehensive decomposition of a firm's performance changes, but is highly relevant in regulatory and other applications, where comparative performance measurement is appropriate. 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. Section 2 discusses the potential application of index number techniques for measuring profitability, productivity and price performance in a binary context. Section 3, then considers the methodology necessary to empirically apply this approach in a multilateral setting, whereas section 4 discusses the data that were used in this study. The following section provides an application of this methodology followed by a discussion of empirical results. The last section offers some conclusions.

## **2. Profitability, Productivity and Price Performance: A Theoretical Illustration With Bilateral Indices**

Saal & Parker (2001) demonstrates an index number approach to decompose a firm's economic profitability change into TFP change and TPP change. For any given firm, this methodology allows identification of the relative contributions of productivity and price performance to observed profit change and the paper illustrates how changes in regulatory policy influenced both the productivity and price performance of regulated water and sewerage companies (WaSCs) in England and Wales (E&W). Nevertheless, while this methodological approach has the strong advantage of allowing the decomposition of profit change even if data is only available for a single firm, it only allows comparison of cross firm differences in the rate of change of TFP, TPP and profitability. Therefore, the lack of any link between firms' indices makes it impossible to measure differences in the level of TFP, TPP and profitability across firms. The implication of this limitation is highlighted if one notes that Saal & Parker (2001) considers an industry subject to price cap regulation in which prices are set using a comparative yardstick regime that measures firm performance levels relative to other regulated firms, but it does not in fact provide a methodology that allows for measurement of such performance differences. This

paper therefore proposes an extension of Saal & Parker (2001) that allows for measurement of a firm's TFP, TPP and profit performance relative to its peers and across time.

Before proceeding, we note that Grifell-Tatje & Lovell (1999) demonstrate a profit decomposition approach, dependent on frontier estimation techniques such as DEA or SFA that decomposes a firm's profitability change while accounting for efficiency catch up relative to the estimated frontier technology. However, while we find no fault with this methodology per se, we note two potential limitations. Firstly, as this approach relies on frontier estimation techniques to obtain measures of relative performance, its application is limited by the requirement of having a sufficient number of degrees of freedom to estimate a meaningful DEA or parametric frontier. In contrast, the empirical index number methodology we propose in Section 3 can be applied to decompose profitability growth regardless of the number of inputs and outputs specified, even in cases where the number of observations is extremely limited. Secondly, while the approach of Grifell-Tatje & Lovell (1999) allows for the impact of differences in relative performance on the production side, it has not, to our knowledge, yet been extended to allow for differences between firms in price performance. We feel such distinctions are important, particularly in the regulatory context.

In this section we first illustrate our index number based approach using an example based on bilateral comparisons between two observations. We first illustrate unit specific, spatial and relative indices of economic profitability and their decomposition. We also employ these binary indices to illustrate how unit specific profitability change can be decomposed as a function of the profitability growth of a base firm and profitability catch-up relative to that firm over time. After this illustration, Section 3 will tackle the thornier issue of applying these concepts in an empirical multilateral setting.

### **2.1. Unit specific Profitability, Productivity and Price Performance Indices**

We first define the unit specific decomposition of profitability following the approach of Saal & Parker (2001) as originally illustrated in Waters & Tretheway (1999). This approach links profits, productivity and price performance between two

time periods, year  $t$  and the base year 1 for firm  $i$ . It therefore only measures differences in the temporal dimension for the given firm.

We define economic profits of firm  $i$  at the base year 1,  $\Pi_{i,1}$ , 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:

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

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. Such unit specific measures provide useful information with regard to both changes in unit specific performance as well as its sources.

## 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.

We define the economic profits of the base firm  $b$  at time  $t$ ,  $\Pi_{b,t}$ , 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:

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

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  $TFP_{i,t}^S = Y_{i,t}^S / X_{i,t}^S$  and  $TPP_{i,t}^S = P_{i,t}^S / W_{i,t}^S$  these indices can be further decomposed as functions of the spatial output ( $Y_{i,t}^S = Y_{i,t} / Y_{b,t}$ ), input ( $X_{i,t}^S = X_{i,t} / X_{b,t}$ ), output price ( $P_{i,t}^S = P_{i,t} / P_{b,t}$ ) and input price ( $W_{i,t}^S = W_{i,t} / W_{b,t}$ ) 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 therefore should have potential applications in regulatory settings on this basis alone. However, spatial measures also contain information on relative performance across firms, which unit-specific indices do not. Spatial performance indices can therefore also 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:

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

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  $TFP_{i,t}^C = Y_{i,t}^C / X_{i,t}^C$  and  $TPP_{i,t}^C = P_{i,t}^C / W_{i,t}^C$  these indices can be further decomposed as functions of catch up indices for outputs ( $Y_{i,t}^C = Y_{i,t}^S / Y_{i,1}^S$ ), inputs ( $X_{i,t}^C = X_{i,t}^S / X_{i,1}^S$ ), output prices ( $P_{i,t}^C = P_{i,t}^S / P_{i,1}^S$ ) and input prices ( $W_{i,t}^C = W_{i,t}^S / W_{i,1}^S$ ). 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. Thus, evidence of improved relative profitability cannot be taken as definitive evidence of improved productivity performance.

### 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 time 1. 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:

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

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.

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

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  $W_{i,t}^S = W_{i,t}^R / W_{b,t}^R$  :

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

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.

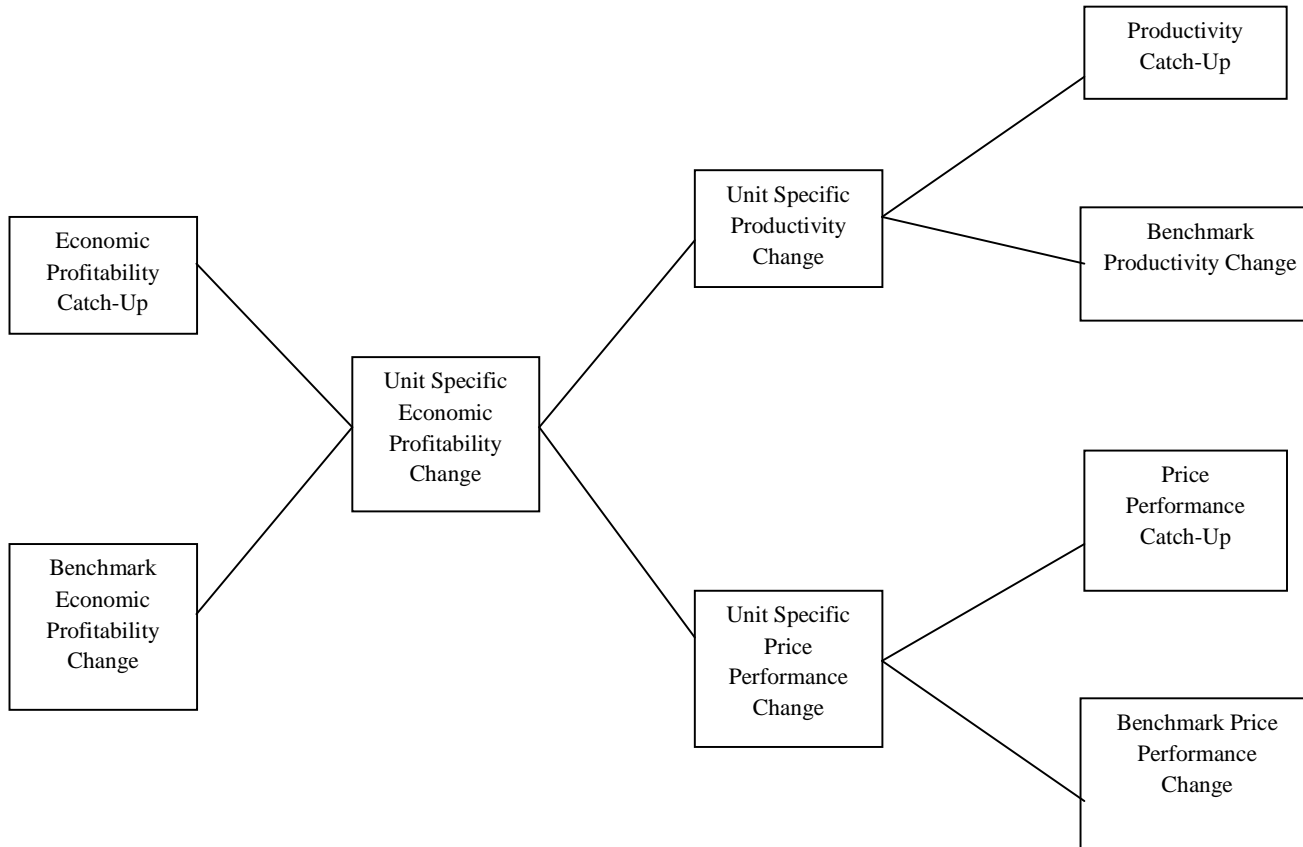
$$\pi_{i,t}^C = \frac{\pi_{i,t}^S}{\pi_{i,1}^S} = \frac{\frac{\pi_{i,t}^R}{\pi_{b,t}^R}}{\frac{\pi_{i,1}^R}{\pi_{b,1}^R}} = \frac{\pi_{i,t}^R}{\pi_{i,1}^R} \times \frac{\pi_{b,1}^R}{\pi_{b,t}^R} = \frac{\pi_{i,t}^{US}}{\pi_{b,t}^{US}} \quad (7)$$

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

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

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. If  $\pi_{i,t}^C > 1$ , then firm  $i$  improved its economic profitability relative to the base firm

over time, whereas  $\pi_{i,t}^C < 1$  implies that relative profitability of firm  $i$  has declined relative to that of the base firm. Moreover, as (8) also demonstrates,  $\pi_{i,t}^{US}$  can be further decomposed to measure not only the relative contributions of unit specific measures of price performance and productivity to profitability, but also to measure these unit specific changes relative to change in TFP and TPP for the base firm. Thus, for example 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 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” or “benchmark” firm. The decomposition of the unit specific profitability change in equation (8) can be visualized in figure 1. Temporal economic profitability change can be expressed as a function of the profitability growth of the benchmark firm and the profitability catch-up relative to the benchmark firm. Moreover, unit specific economic profitability change can be further decomposition into a unit specific productivity and price performance change. The former can be expressed as a function of a function of the productivity growth of the benchmark firm and the productivity catch-up relative to the benchmark firm, whereas the latter can be expressed as a function of the price performance growth of the benchmark growth and the price performance catch-up relative to the benchmark firm. Our next section therefore discusses a methodological approach that allows the actual application of the bilateral concepts detailed above in an empirical multilateral setting.



**Figure 1 Decomposition of Unit Specific Economic Profitability Change**

## 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 calculate chained unit-specific profitability, productivity and price performance 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  $X_{i,t}$ , :

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

where  $Y_t^m$  and  $Y_1^m$  denote the quantities for the  $m$ th output for periods  $t$  and 1 respectively, whereas  $X_t^n$  and  $X_1^n$  present the quantities for the  $n$ th inputs for periods  $t$  and 1 respectively. Moreover,  $P_t^m$  and  $P_1^m$  are the prices for  $m$ th 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 Laspeyres 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):

$$TFP_{i,t} = \frac{Y_{i,t}}{X_{i,t}} \quad (10)$$

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:

$$Y_{i,t}^{CH} = 1 \times Y_{i,1,2} \times Y_{i,2,3} \times \dots \times Y_{i,t-1,t} \quad X_{i,t}^{CH} = 1 \times X_{i,1,2} \times X_{i,2,3} \times \dots \times X_{i,t-1,t} \quad (11)$$

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

$$TFP_{i,t}^{CH} = \frac{Y_{i,t}^{CH}}{X_{i,t}^{CH}} \quad (12)$$

The set of  $I \times T$  unit-specific chained productivity, output and input indices over time can then be summarized in the following matrices:

$$TFP^{CH} = \begin{bmatrix} TFP_{1,1}^{CH} & TFP_{1,2}^{CH} & \dots & TFP_{1,T}^{CH} \\ TFP_{2,1}^{CH} & TFP_{2,2}^{CH} & \dots & TFP_{2,T}^{CH} \\ \dots & \dots & \dots & \dots \\ TFP_{I,1}^{CH} & TFP_{I,2}^{CH} & \dots & TFP_{I,T}^{CH} \end{bmatrix} \quad Y^{CH} = \begin{bmatrix} Y_{1,1}^{CH} & Y_{1,2}^{CH} & \dots & Y_{1,T}^{CH} \\ Y_{2,1}^{CH} & Y_{2,2}^{CH} & \dots & Y_{2,T}^{CH} \\ \dots & \dots & \dots & \dots \\ Y_{I,1}^{CH} & Y_{I,2}^{CH} & \dots & Y_{I,T}^{CH} \end{bmatrix}$$

$$X^{CH} = \begin{bmatrix} X_{1,1}^{CH} & X_{1,2}^{CH} & \dots & X_{1,T}^{CH} \\ X_{2,1}^{CH} & X_{2,2}^{CH} & \dots & X_{2,T}^{CH} \\ \dots & \dots & \dots & \dots \\ X_{I,1}^{CH} & X_{I,2}^{CH} & \dots & X_{I,T}^{CH} \end{bmatrix} \quad (13)$$

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,  $(P_{i,t}^{CH})$  is then calculated as  $P_{i,t}^{CH} = R_{i,t}^{US} / Y_{i,t}^{CH}$ . 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,  $(W_{i,t}^{CH})$  is then calculated as  $W_{i,t}^{CH} = C_{i,t}^{US} / X_{i,t}^{CH}$ . Finally, a chained unit-specific TPP index for any firm  $i$  over time,  $(TPP_{i,t}^{CH})$  can be obtained as:



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

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.

Bilateral Fisher output and input indexes between two firms  $i$  and  $j$  in the case of  $m$  outputs and  $n$  inputs are respectively,  $Y_{i,j}$  and  $X_{i,j}$ :

$$Y_{i,j} = \left[ \frac{\sum_{m=1}^M P_j^m Y_i^m}{\sum_{m=1}^M P_j^m Y_j^m} \times \frac{\sum_{m=1}^M P_i^m Y_i^m}{\sum_{m=1}^M P_i^m Y_j^m} \right]^{\frac{1}{2}} \quad X_{i,j} = \left[ \frac{\sum_{n=1}^N W_j^n X_i^n}{\sum_{n=1}^N W_j^n X_j^n} \times \frac{\sum_{n=1}^N W_i^n X_i^n}{\sum_{n=1}^N W_i^n X_j^n} \right]^{\frac{1}{2}} \quad (15)$$

where  $Y_i^m$  and  $Y_j^m$  denote the quantities for the  $m$ th output for firms  $i$  and  $j$  respectively, whereas  $X_i^n$  and  $X_j^n$  present the quantities for the  $n$ th inputs for firms  $i$  and  $j$  respectively.

Moreover,  $P_i^m$  and  $P_j^m$  are the prices for  $m$ th 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 Laspeyres and Paasche output and input indexes. For instance, Laspeyres 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 bilateral Fisher productivity index is then constructed as a ratio of the Fisher output index relative to Fisher input index:

$$TFP_{i,j} = \frac{Y_{i,j}}{X_{i,j}} \quad (16)$$

The above formula is a binary comparison that can be applied directly when we are only interested in making comparisons between two firms. However, when we are interested in making meaningful comparisons between more than two firms, the multilateral nature of spatial comparisons creates some difficulties, which arise from the fact that more than two firms are compared at the same time. Firstly, the number of comparisons may be quite large depending on the number of companies that we have in our sample so the calculation of productivity index can be quite difficult. Secondly, we need consistent comparisons between all firms such that the relative comparisons between any two firms are consistent with other comparisons (transitivity).

Following standard practice, the process of calculating a transitive Fisher output ( $Y_{i,j}$ ) and input ( $X_{i,j}$ ) indices begin by calculating all the possible binary comparisons,  $i, j = 1, \dots, I$  where  $I$  is the total number of companies, and results in the following  $I \times I$  matrices of binary comparisons:

$$\begin{bmatrix} Y_{1,1} & Y_{1,2} & \dots & Y_{1,I} \\ Y_{2,1} & Y_{2,2} & \dots & Y_{2,I} \\ \dots & \dots & \dots & \dots \\ Y_{I,1} & Y_{I,2} & \dots & Y_{I,I} \end{bmatrix} \quad \begin{bmatrix} X_{1,1} & X_{1,2} & \dots & X_{1,I} \\ X_{2,1} & X_{2,2} & \dots & X_{2,I} \\ \dots & \dots & \dots & \dots \\ X_{I,1} & X_{I,2} & \dots & X_{I,I} \end{bmatrix} \quad (17)$$

These binary Fisher indices 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 3<sup>rd</sup> 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:

$$Y_{ij}^S = \prod_{k=1}^I [Y_{ik} \times Y_{kj}]^{\frac{1}{I}} \quad X_{ij}^S = \prod_{k=1}^I [X_{ik} \times X_{kj}]^{\frac{1}{I}} \quad (18)$$

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:

$$TFP_{ij}^S = \frac{Y_{ij}^S}{X_{ij}^S} \quad (19)$$

However, one can also derive fully equivalent transitive Fisher productivity indices using the EKS method by directly taking the geometric mean of all  $I$  possible direct and indirect (through any possible 3<sup>rd</sup> firm  $k$ ) binary Fisher productivity comparisons of firms  $i$  and  $j$ :

$$TFP_{ij}^S = \prod_{k=1}^I [TFP_{ik} \times TFP_{kj}]^{\frac{1}{I}} \quad (20)$$

The resulting index fulfills the transitivity property since it is derived using the EKS method, so any direct comparison between two firms  $i$  and  $j$  is the same with an indirect comparison between these two firms with a third firm  $k$ :

$$TFP_{i,j}^S = TFP_{i,k}^S \times TFP_{k,j}^S \quad \forall i, j \quad (21)$$

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:

$$TFP_i^S = \frac{Y_i^S}{X_i^S} \quad (22)$$

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:

$$TFP_{i,t}^S = \frac{Y_{i,t}^S}{X_{i,t}^S} \quad (23)$$

These  $I \times T$  measures then form the elements of a complete set of spatial comparisons indicating the productivity, output and input of firm  $i$  relative to the base firm at time  $t$ , and can be succinctly illustrated in matrices similar to those for unit-specific chain indices depicted in (13).

We now turn our discussion to the construction of the spatial total price performance index,  $(TPP_{i,t}^S)$ . Firstly, we express turnover of a firm  $i$  relative to the base firm as  $R_{i,t}^S = R_{i,t} / R_{b,t}$ . The spatially consistent aggregate output price index,  $(P_{i,t}^S)$  is then calculated as  $P_{i,t}^S = R_{i,t}^S / Y_{i,t}^S$ . Similarly, we express nominal economic costs of a firm  $i$  relative to the base firm as  $C_{i,t}^S = C_{i,t} / C_{b,t}$ . The spatially consistent aggregate input price index,  $(W_{i,t}^S)$  is then calculated

as  $W_{i,t}^S = C_{i,t}^S / X_{i,t}^S$ . Finally, a spatially consistent TPP index of any firm  $i$  relative to the base firm at any given time  $t$ ,  $(TPP_{i,t}^S)$  can be obtained as:

$$TPP_{i,t}^S = \frac{\frac{R_{i,t}^S}{Y_{i,t}^S}}{\frac{C_{i,t}^S}{X_{i,t}^S}} = \frac{P_{i,t}^S}{W_{i,t}^S} \quad (24)$$

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  $b$ ,  $TPP_{i,t}^S$ . Finally, we also compute matrices of  $I \times T$  measures that include the spatial TPP, output and input prices and economic profitability comparisons across companies at any given year.

### 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.<sup>2</sup>

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

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<sup>2</sup> 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

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). 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:

$$TFP_{i,t}^R = \left[ \prod_{j=1}^I \left[ (TFP_{j,t}^{CH} \times TFP_{j,1}^S) \times \frac{TFP_{i,t}^S}{TFP_{j,t}^S} \right] \right]^{\frac{1}{I}} \quad (25)$$

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  $TFP_{i,t}^R$  in (25) 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  $X_{i,t}^R$ . The resulting measures of the relative productivity, output and input change of any firm over time can be depicted in matrices similar to those in (13) and (24).

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,  $(P_{i,t}^R)$  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,  $(W_{i,t}^R)$  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,  $(TPP_{i,t}^R)$  can be obtained as:

$$TPP_{i,t}^R = \frac{\frac{R_{i,t}^R}{Y_{i,t}^R}}{\frac{C_{i,t}^R}{X_{i,t}^R}} = \frac{P_{i,t}^R}{W_{i,t}^R} \quad (26)$$

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 (25) and (26). 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  $Y_{i,t}^{US} = \frac{Y_{i,t}^R}{Y_{i,1}^R}$  and  $X_{i,t}^{US} = \frac{X_{i,t}^R}{X_{i,1}^R}$ . In an analogous manner, consistent

measures of unit-specific TPP output price, input price and economic profitability indexes are

$$\text{respectively, } TPP_{i,t}^{US} = \frac{TPP_{i,t}^R}{TPP_{i,1}^R}, P_{i,t}^{US} = \frac{P_{i,t}^R}{P_{i,1}^R}, W_{i,t}^{US} = \frac{W_{i,t}^R}{W_{i,1}^R} \text{ and } \pi_{i,t}^{US} = TFP_{i,t}^{US} TPP_{i,t}^{US} .$$

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  $\left[ \prod_{i=1}^I (TFP_{i,t}^{CH}) \right]^{\frac{1}{I}} = \left[ \prod_{i=1}^I (TFP_{i,t}^{US}) \right]^{\frac{1}{I}}$ , and

$$\left[ \prod_{i=1}^I (TPP_{i,t}^{CH}) \right]^{\frac{1}{I}} = \left[ \prod_{i=1}^I (TPP_{i,t}^{US}) \right]^{\frac{1}{I}} .$$

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. We firstly, calculated chained productivity, price performance and profitability indices for each firm over time. Then, we derived spatial productivity, price performance and profitability indices across firms for each year. Then by reconciling together temporal chained and spatial indices, we were able to derive relative productivity, price performance and profitability 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 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, our index number methodology does not allow us to as readily take into account differences in operating characteristics that may affect relative measures of productivity or price performance. Nevertheless, given that profitability is not influenced by these characteristics, and if differences in operating characteristics are relatively small, the methodology should be robust enough to accurately characterize trends in regulatory performance over time.

#### **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.<sup>3</sup> 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

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<sup>3</sup> 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.

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.

## **5. Results From Productivity, Price Performance and Profitability Computations**

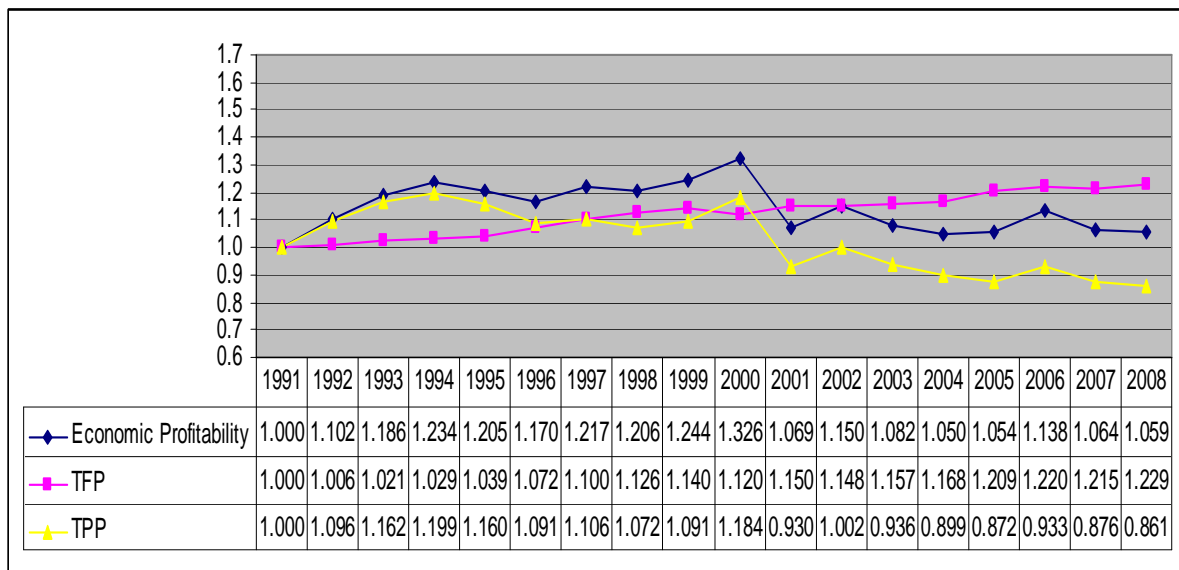
The above spatial and relative profitability, productivity and price performance measures were defined relative to the base firm in the sample. However, if the base firm is defined as the firm with the highest productivity in the sample, then each firm's productivity, prices and profits will be relative to this best practice or benchmark firm.<sup>4</sup> In this section we first report geometric average measures of unit-specific profitability, productivity and price performance in figure 2. Subsequently, we demonstrate the further decomposition that is facilitated by our methodological approach by decomposing these changes into an average catch-up component and the performance of the benchmark firm.

Figure 2 illustrates the decomposition of unit-specific economic profitability change into unit-specific productivity and price performance change over the period 1991-2008, thereby replicating the work of other authors including Saal and Parker (2001), which provided measures of unit-specific economic profitability, productivity and price performance for WaSCs over 1985-1999 using a Tornqvist index. The results indicate that between 1991 and 2008, average economic profitability increased by 5.9%, which was attributed to an improvement in TFP of 22.9% and a reduction in TPP of 13.9%. On average there was a stable 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 1991-1994, 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

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<sup>4</sup> 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 this 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.

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 rise steadily. Our finding therefore confirms Saal and Parker’s (2001) study, which found that during 1991-1999, positive changes in economic profitability were mainly attributed to changes in TPP rather in TFP. However, figure 2 extends their study by including results for unit-specific profitability, productivity and price performance changes until 2008.



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

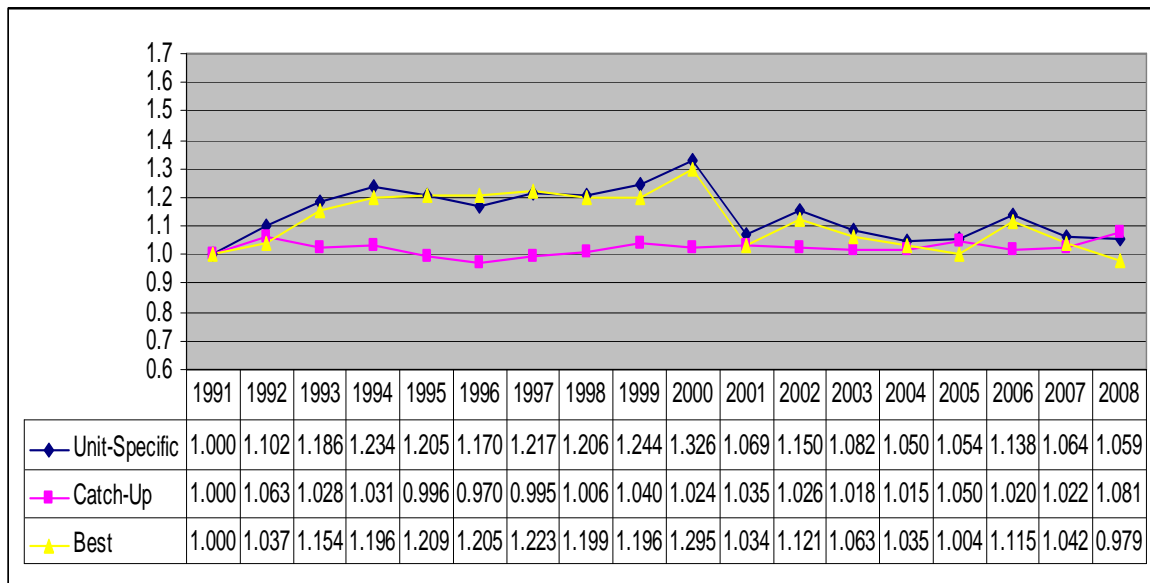
These extended results demonstrate that after 2000, reduced output prices caused TPP to dramatically decline, and its value remained consistently below 1 after 2000. This indicates that regulatory price changes implemented after 2000, caused the price performance of firms to fall substantially below 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 though 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 continued to follow the trend of TPP, indicating that changes in price performance continue to be the main determinant of changes in economic profitability.

Nevertheless, while TPP fell below 1991 levels after 2000 average economic profitability did not, thereby implying that on average profitability in the industry remained moderately higher than in the immediate aftermath of privatization. This is because of the significant and continuing gains in TFP between 1991 and 2000 that more than offset the dramatic tightening of regulated output prices in 2001. Thus, the immediate impact of the 1999 price review in 2001 is consistent with an interpretation emphasizing that Ofwat chose to pass considerable accumulated past productivity improvements to consumers, thereby worsening profitability, but still left the industry more profitable than in 1991. Moreover, the steady decline in average price performance, gains in TFP and relatively stable economic profitability that have characterized the 2001-2008 period, suggests that Ofwat is now more focused on passing productivity benefits to consumers, and maintaining stable profitability than in the earlier regulatory periods.

Our discussion of figure 2 has clearly illustrated the decomposition of unit-specific economic profitability change into unit-specific productivity and price performance change and also demonstrates that this approach can capture the significant shift in regulatory practice after 2000. However, given that Ofwat operates a system of yardstick regulation which is designed to encourage catch up to benchmark firm performance, the methodology developed above, is particularly relevant. Thus, we should expect that the performance improvement of laggard firms should exceed that of benchmark firms. This is because the price caps set for benchmark firms should only require them to continue improving their performance through technical change, while price caps for non benchmark firms will also require them to catch up to the benchmark firm. Thus, the multilateral models developed above can be used to illustrate the contribution of benchmark performance and average catch-up to average firm performance.

Looking at figure 3, we note that the lax price caps set at privatization as documented in past studies, allowed average economic profitability to increase significantly until 1994 by 23.4% and that this exceeded benchmark economic profitability growth which increased by 19.6%, therefore allowing an average catch-up to benchmark profitability of 3.1%. The tightening of price caps from 1994 resulted in a downward trend for average and benchmark economic profitability. Thus, during the years 1995-1998, the average firm did not improve its economic profitability relative to the benchmark but this was once again interrupted during 1998-2000, when average economic profitability increased more than benchmark profitability,

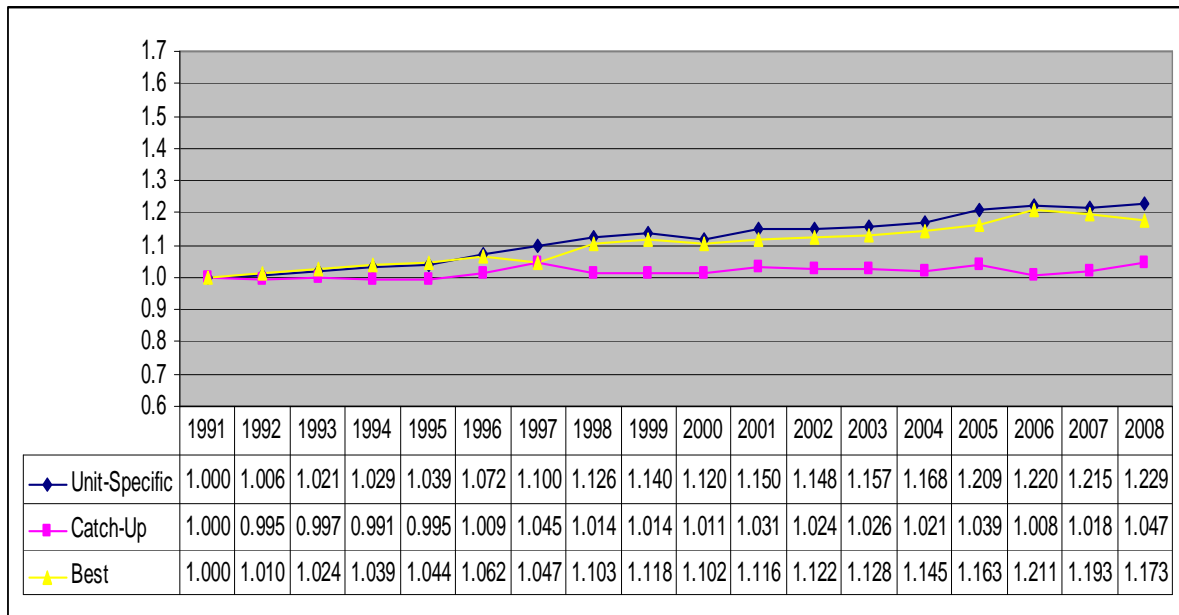
allowing average catch-up of 2.4%. The substantial reduction in output prices due to the tightened 1999 price review resulted in a significant reduction in average and benchmark economic profitability for the subsequent years which showed an upward trend only in 2002 and in 2006. We note that benchmark firm realized significant decline in its economic profitability in 2001, and despite an improvement in 2002, further declines meant that its profitability in 2005 was only 0.04% of its level in 1991. Moreover, despite an uptick of benchmark profitability to 1.115 in 2006, by 2008 benchmark profitability was only 97.9% of its 1991 level. In contrast, while average economic profitability was also considerably lower after 2000, it has never declined below average 1991 levels. As a result, average firm showed high levels of catch-up in profitability relative to the benchmark after 2001. However, this is mainly explained by the relative decline in the economic profitability of the benchmark firm. Thus, over the 1991 to 2008 period the average company caught-up to benchmark economic profitability by 8.1%, but this was mainly attributable to a decline in benchmark profitability of 2.1%.



**Figure 3 Decomposition of Average Unit-Specific Profitability into Average Profitability Catch-Up and Profitability of the Benchmark Firm**

The decomposition of average unit-specific productivity growth into productivity change of the benchmark firm and average productivity catch-up relative to the benchmark firm is depicted in figure 4. Until 1995 there were 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 4.4%. This finding suggests that the lax price caps set at privatization encourage neither average or benchmark firms to achieve high productivity levels. This trend was interrupted after 1995 when both average and benchmark productivity performance significantly improved. We note that during the years 1996-2000 when price caps were first tightened, average companies should have had stronger incentives to catch-up to benchmark, while the benchmark company should also have been 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 improvement of 10.2%, thereby indicating total catch-up in productivity of 1.1% 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 2.1%, while the benchmark firm improved its productivity by 14.5%. 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. Thus, in sum over the entire 1991-2008 regulatory period, average productivity improved by 22.9%, while benchmark productivity improved its productivity by 16.6% allowing an average productivity catch-up of 4.7%. Moreover, our results suggest that 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.

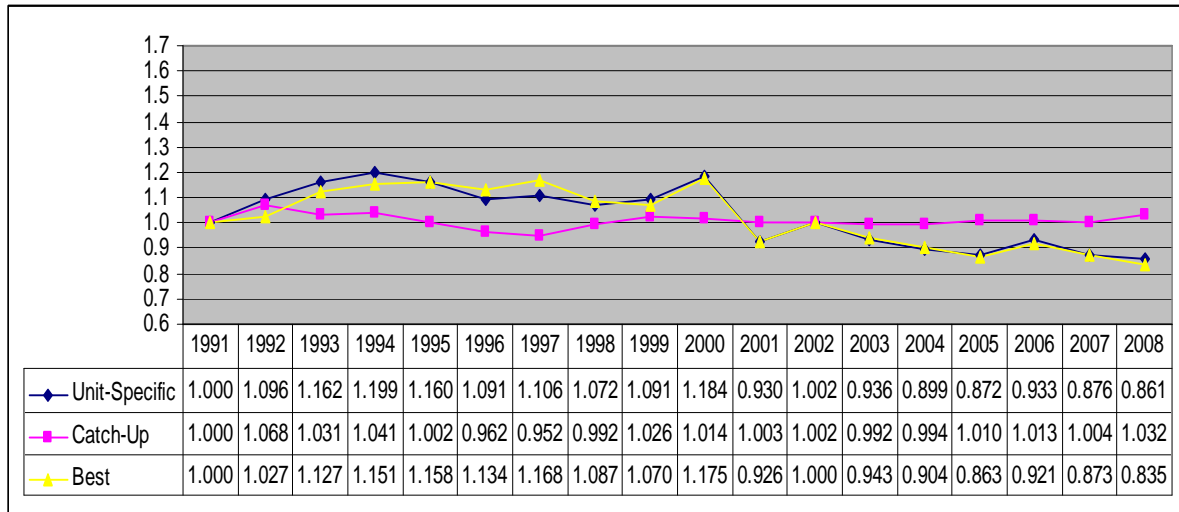


**Figure 4 Decomposition of Average Unit-Specific TFP Change into Benchmark TFP Change and Average Catch-Up to the Benchmark Firm**

The decomposition of average unit-specific economic price performance change into the price performance change of the benchmark firm and average price performance catch-up relative to that firm over time is displayed at figure 5. The results indicated that until 1994 when price caps were relatively lax, both average and benchmark price performance significantly increased by 19.9% and 15.1% respectively. Average TPP growth exceeded benchmark TPP growth allowing an average catch-up in price performance of 4.1%. The tighter 1994 price review, led to a substantial downward trend in average and benchmark TPP until 1998. We note that during the years 1996-1998 benchmark TPP growth exceeded average TPP growth and therefore there were not any price performance catch-up gains on average. After 1998, average TPP increased more than benchmark TPP but by 2000, there was a broad convergence in average and benchmark TPP as the respectively demonstrated cumulative increases of 18.4% and 17.5% since 1991. However, the dramatic impact of the 1999 price review obliged the companies to reduce their output prices significantly and after 2000 there was a significant decline in average and benchmark TPP, except for the year 2006 when relatively looser price caps were introduced. We notice that during the years 2001-2004, there was little or no difference between average and benchmark TPP, while during the years 2005-2008 average TPP exceeded benchmark TPP



showing the highest levels of price performance catch-up in 2006 and in 2008. By 2008, average TPP had been reduced by 13.9% relative to 1991 levels, while benchmark TPP had been reduced even more by 16.5%, thereby allowing an average catch-up in price performance of 3.2%. Thus, figure 5 clearly illustrates that in the post 1999 price review period, the price performance of all firms is substantially lower than in the first 10 years after privatisation.



**Figure 5 Decomposition of Average Unit-Specific TPP Change into Benchmark TPP Change and Average Catch-Up to the Benchmark Firm**

## 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 employed a panel index number technique to decompose profits into total factor productivity and price performance, and demonstrated several different but theoretically related methods to link productivity, price performance and profitability. Thus, we not only estimated and decomposed unit-specific (temporal) profitability of each firm over time, but also illustrated a multilateral spatial Fisher index, that allowed multilateral spatial measures between all the pairs of companies included in the analysis at any given year (multilateral spatial comparisons). We also linked together the spatial and temporal results in order to derive estimates of relative productivity, price performance and profitability measures over time. This allowed us to express the unit-specific profitability of any firm as a function of the profitability growth of the benchmark firm and actual catch-up to the benchmark

firm. Further decomposition included other productivity and price performance components as well.

The results indicated that during the years 1991-2008, on average there was a stable increase in TFP, while TPP followed an upward trend until 1994, due to the lax price caps set at privatization, but was interrupted in 1995 due to the tightened 1994/95 price review and was followed by a substantial increase in 1999 and 2000. After 2000, average TPP and economic profitability followed the same trend, whereas average TFP increased steadily. Average TPP and profitability significantly declined due to the tightened 1999/00 price review and followed a downward trend except for the years 2002 and 2006. Thus, after 2001, the steady decline in average price performance, gains in TFP and relatively stable economic profitability suggested that Ofwat was more focused on passing productivity benefits to consumers, and maintaining stable profitability than in the earlier regulatory periods.

Focusing on economic profitability results it is concluded that average economic profitability exceeded benchmark economic profitability during the years 1991-1994 and 1998-2008, showing high levels of catch-up relative to benchmark economic profitability after 2001, which was mainly attributed to the relative decline in the economic profitability of the benchmark firm. With respect to the productivity performance of the less productive and benchmark firms, it is concluded that until 1995 average and benchmark firms did not have strong incentives to achieve high productivity levels. This was interrupted after 1995, when price caps became tightened providing evidence that less productive firms had stronger incentives to catch-up to benchmark, while the benchmark company was also incentivized to continue to improve its productivity. Significant productivity gains for the average firm relative to the benchmark also continued after 2000. Thus, our results suggested that when Ofwat's tight price reviews in 1995 and especially in 1999/00 incentivize the companies to improve their productivity performance. Also, looking at the average and benchmark price performance we concluded by 2000 there had been a convergence in average and benchmark TPP. During the years 2001-2004, there was little or no difference between average and benchmark TPP and during the years 2005-2008 average TPP exceeded benchmark TPP showing the highest levels of price performance catch-up in 2006 and in 2008. Our results suggested that in the post 1999

price review period, the price performance of all firms was substantially lower than in the first 10 years after privatisation.

Overall, our index number based approach provided a backward-looking approach with respect to the impact of price cap regulation on the profitability, productivity and price performance of less productive and benchmark firms. It allowed us to calculate unit-specific profitability, TFP and TPP change and provide spatially consistent measurement of changes in these performance measures relative to other firms even if the number of available observations was extremely limited. Another research paper will explore the impact of operating characteristics such as drinking water and sewerage treatment quality, on profitability, TFP and TPP measures. Moreover, we strongly believe that our methodology can be further used to aid 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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