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PRODUCTIVITY IMPROVEMENT IN THE WATER AND SEWERAGE INDUSTRY IN ENGLAND SINCE PRIVATISATION

Final Report for Water UK

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1 INTRODUCTION

Water UK has commissioned Frontier Economics to quantify the productivity gains achieved by the water and sewerage companies in England since privatisation in 1989. To undertake this work, Frontier Economics has estimated the Total Factor Productivity (TFP) growth achieved by the industry between 1992/93 and 2016/17. Our work is based on an update of previous work published by Saal & Parker (2001)[1]. Notwithstanding the limited timescale of the project, the study has also sought to explore the potential for extending the analysis through further sensitivity of the model to different assumptions, and through the development of new techniques.

Frontier Economics has completed this work in collaboration with Professor David Saal of the Centre for Productivity and Performance at Loughborough University, who is a leading expert in productivity analyses in the UK. The work has been independently reviewed by Professor Tom Weyman-Jones.

1.1 What is productivity

At the simplest level productivity is the ratio of the quantity of outputs produced to the quantity of inputs used in production. That is:

Productivity = Quantity of outputs/Quantity of inputs[2]

Therefore, productivity will increase when fewer inputs are used to produce a given level of output, or alternatively, when the quantity of output increases for a given level of inputs. Similarly, productivity will decline if more inputs are required to produce a given level of output, or alternatively, for a given level of inputs the quantity of output declines.

Important sources of productivity gains are efficiency improvements (i.e. fewer resources are needed as they are used more efficiently given the existing technology), technological change which reduces the efficient level of inputs required and/or improves the characteristics and quality of the outputs produced, and changes in the operating environment.

A measure of total factor productivity (TFP) aims to capture all the outputs produced by an entity and all the inputs used to produce those outputs.

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[1] Saal & Parker (2001), 'Productivity and Price Performance in the Privatized Water and Sewerage Companies of England and Wales', July. See: https://link.springer.com/article/10.1023/A:1011162214995

2 The OECD has the following definitions:

Total or Multifactor productivity (TFP, MFP): Relates a change in output to several types of inputs. MFP is often measured residually as that change in output that cannot be accounted for by the change in combined inputs.

Productivity change: Conceptually, the combined effects of changes in technical efficiency, allocative efficiency, disembodied technical change and economies of scale. When measured residually, additional factors bear on the residual, in particular the rate of capacity utilisation and measurement errors.

OECD (2001), Measuring Productivity - OECD Manual: Measurement of Aggregate and Industry-level Productivity Growth, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264194519-en

It is acknowledged that standard approaches to productivity growth analysis, focussing on the change in quantity of outputs, may not always capture productivity improvements arising from an increase in the quality of outputs. This is an important factor in the water and sewerage industry.

Adjustments for quality present significant challenges. We are comfortable that the approach to quality adopted in this study is fit for purpose and reasonable. We consider that the approach is conservative but if time and data constraints were lifted it would be possible to develop alternatives that are potentially more accurate. We describe these alternatives later in this report.

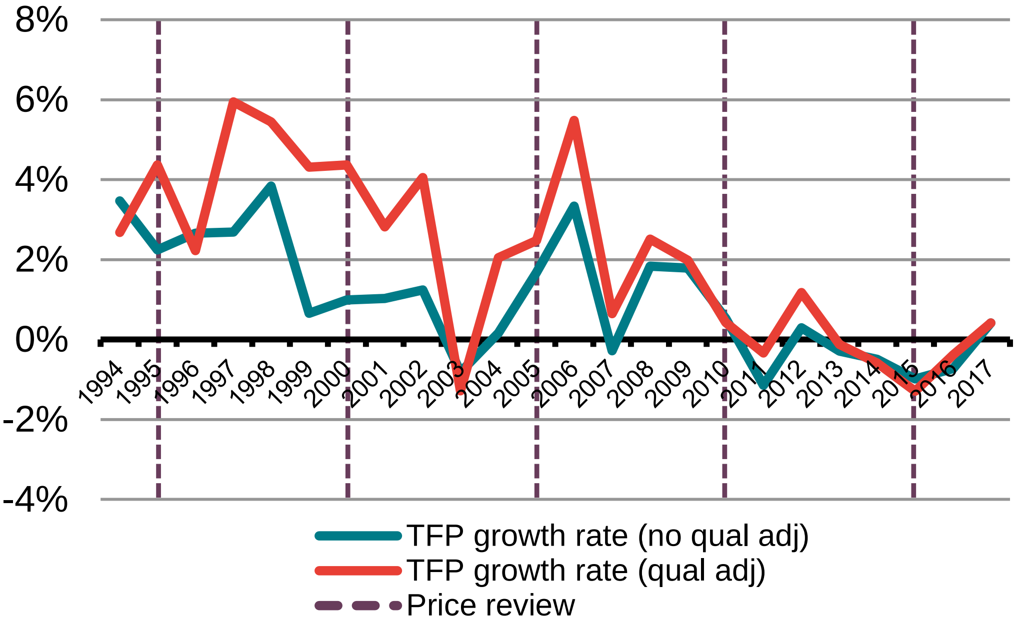
1.2 Summary of results

Productivity gains achieved by the water and sewerage industry since privatisation

Annual productivity growth for the water and sewerage sector has averaged 2.1% since privatisation when adjusting, on a conservative basis, for output quality.

Productivity growth was high during the immediate post-privatisation period, then followed a period of intermediate growth in the first five years of the 2000s, with a significant drop in growth since 2007 following the Global Financial Crisis (GFC). Estimates since 2015 should be viewed more cautiously as they are influenced by some data inconsistencies due to changes in reporting. Quality adjustments have also been made particularly conservatively in this period due to lack of data.

Figure 1 Annual productivity estimate, 1994-2017



Source: Frontier Economics

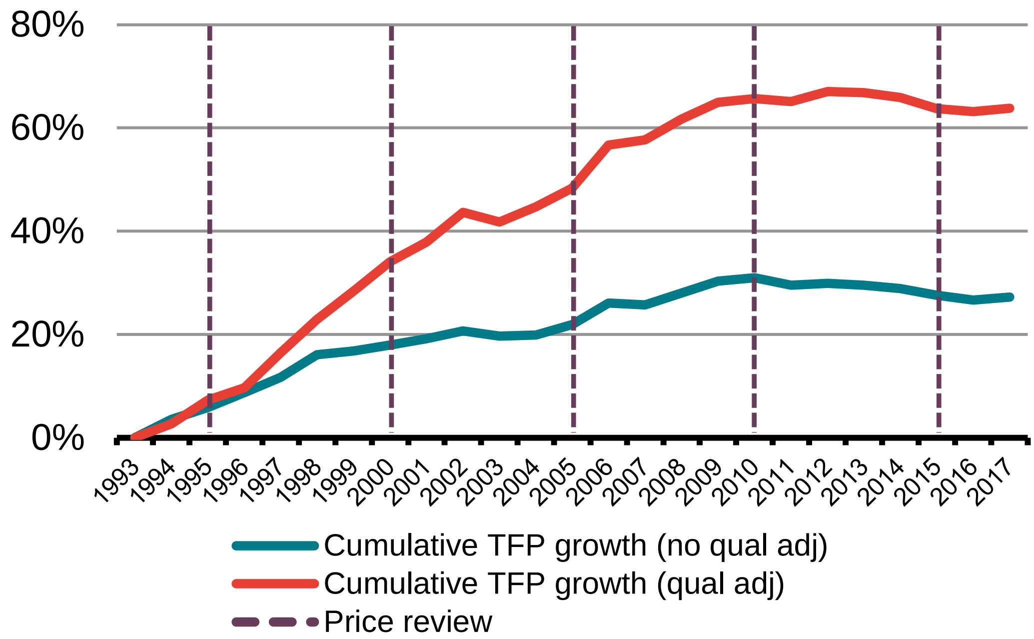
Figure 2 Annual TFP growth estimates over price review periods

Period	TFP average growth (no quality adjustment)	TFP average growth (quality adjustment)
1994-1995	2.9%	3.5%
1996-2000	2.2%	4.5%
2001-2005	0.7%	2.0%
2006-2010	1.4%	2.2%
2011-2015	-0.5%	-0.2%
2016-2017	-0.2%	0.0%
1994-2008 Business Cycle 1	1.6%	3.2%
2009-2017 Business Cycle 2 (ongoing)	-0.1%	0.1%
1994-2017	1.0%	2.1%

Source: Frontier Economics

While annual productivity growth can be seen to fluctuate from year to year, and the annual growth rate to have declined, it is clear that estimated cumulative productivity has shown an upward trend over almost the whole period (see Figure 3 below). Cumulative TFP growth over the period of analysis has increased by 64% over the period of analysis on a quality adjusted basis, and 27% on the most conservative basis without quality adjustment.

Figure 3 Cumulative TFP growth, 1993-2017



Source: Frontier Economics

Note: Relative to TFP in 1993

The impact of quality adjustment on productivity growth

With no adjustment for output quality, the average annual productivity growth since privatisation was 1% to 2017. As currently estimated and illustrated in Figure 1, the impact of quality improvements appears to diminish since 2005.

However, this partly reflects the conservative measures of quality that were used for the analysis given data availability. The measures we have used to capture quality improvements reflected the focus of investment in the earlier period under review. The emphasis of quality investment in later years has focussed on other dimensions which are not well captured by the measures included in this study, due to the shortage of comparable data on these dimensions covering the whole period.

The chart also suggests that quality improvements were particularly significant in productivity growth in the 5 years from 1997 to 2002. This may reflect some natural and expected lag between investment and quality outcomes being achieved.

Productivity gains achieved in comparator sectors of the economy

Our analysis of productivity growth in comparator sectors suggests that the water and sewerage businesses have outperformed materially those comparators in the decades after privatisation and leading up to the GFC in 2008. Since then, the UK's productivity growth and the productivity growth of comparator sectors has been negative. The water sector has not been immune to this trend, with productivity growth materially slower than in the post privatisation period, but the water and sewerage businesses have nonetheless delivered modest positive productivity growth.

Value of productivity improvements delivered

To provide some further context to our results, it may be helpful to consider the reduction in cost that has resulted owing to TFP growth.

In our model we estimated aggregate industry economic costs to be £9.98 billion in 2017. Our estimate of quality unadjusted cumulative TFP growth of 1.27 implies that aggregate input usage (and hence cost in the industry) would have been 27% higher than at present, i.e. £2.72 billion higher at £12.70 billion, had no TFP growth been achieved over the period. While this may be regarded as an underestimate of the actual economic cost savings that have been made, given substantial improvements in quality in the industry, we prefer to emphasize this figure as providing a more conservative estimate for the total savings that can be attributed to productivity growth since 1993. We note that this estimate of reduced economic cost is derived versus a counterfactual of zero TFP growth.

1.3 Structure of the report

The rest of the report is laid out as follows:

- Section 2 – TFP growth analysis of the water and sewerage industry in England since privatisation.
- Section 3 – TFP growth analysis of comparator sectors
- Section 4 – Productivity gains identified from literature review.
- Section 5 – Proposed refinements and next steps, including alternative approaches that may be pursued in the future

Further information on the data sources and our literature review are contained in Annexes A to C.

2 TFP GROWTH ANALYSIS OF THE WATER AND SEWERAGE INDUSTRY IN ENGLAND SINCE PRIVATISATION

In this report we estimate TFP growth for the water and sewerage sector, as defined in Section 1.1.

In Section 2.1 below we outline how inputs and outputs are measured in this study. In Section 2.2 we describe how the basic productivity growth index is constructed. In Section 2.3 we outline how this is adjusted for improvements in quality of service. In Section 2.4 we summarise our TFP growth results. Annex A summarises data sources and issues and where our approach adapts the Saal & Parker approach from 2001.

2.1 Measurement of outputs and inputs

Outputs

The water and sewerage industry is by definition a multi-output industry, characterised by two key outputs, water services and sewerage services. In constructing our TFP growth index for the last 25 years or so, we require appropriate measures of each that are broadly consistent over the time period.

Previous studies have represented outputs by measures of connected properties and/or physical volumes of water usage/sewage produced. The Saal & Parker approach in 2001, which we are updating here, selected connections as the output measure due to data limitations with volumetric demand measures. We also adopt this approach.[3]

These measures (or proxies) of output for water and sewerage services do not fully capture the quality of service. For instance:

- for the water service, the safety of drinking water in terms of chemical composition, and also the reliability of service, and 'aesthetic' qualities such as colour and taste; and
- for the wastewater service, the impact of sewage treatment works on the river and bathing waters into which they discharge treated water as well as the frequency with which customers experience sewer flooding.

Capturing quality robustly in a TFP growth study is challenging. There are numerous ways in which quality aspects might be captured. In our index-based approach to TFP growth estimation we again follow Saal & Parker, in treating these quality aspects separately by way of an adjustment to our output indices.

[3] It was noted in Saal & Parker that some demand measures suffered a downward bias due to recent efforts to reduce leakage. However, in future work there may be merit in appraising TFP using demand measures, if these can be collected on a consistent basis. When long periods of time are studied, ensuring consistency in data reporting is inevitably challenging. In Section 5 we provide further discussion of the potential for such sensitivity analysis.

The methods adopted are further discussed in section 2.3 below, along with future alternatives.

Inputs

TFP growth indices by definition, and in contrast to partial factor productivity growth indices, consider productivity by reference to all factors of production: capital, labour, materials and fuel usage are the key inputs to the water and sewerage sector. Factors of production can be identified either as physical measures of inputs or value measures of costs, deflated by an appropriate price index. In developing input measures the important methodological principle to follow is the 'total regulated economic cost approach', in order to capture the true value of input costs to society.

Saal & Parker simplified the analysis to capital inputs and two dimensions of operating input costs: labour and other input costs. In our current approach we have followed Saal & Parker, but have simplified further to capital and 'operating' inputs, combining labour and other inputs. The main driver for this simplification is a practical one, around the availability of data for labour and other inputs on a consistent basis over the entire period.

There are two potential detriments that arise from this simplification. First, our approach creates an inability to decompose the origins of TFP changes to such a granular extent. Since our remit is to measure TFP growth at an aggregate level, rather than to present a granular appraisal of its origins, this is not a concern.4 There is also a potential philosophical drawback to this method as our simplified 'opex/capex' approach removes a physical proxy of input usage (labour) and implies that operating input trends are to a large extent determined by the chosen price deflator used for opex trends. Again, we do not consider that this compromises the integrity of our results.

For capital inputs we have taken the following approach.

The index requires an estimate of the capital stock in each period. This is complicated in the water and sewerage industry by the 'Regulatory Capital Value (RCV) discount'. This means that the RCV itself does not reflect the stock of actual physical investment, as RCVs are based on the privatisation value adjusted for net additions to the capital stock since. As the privatisation value was well below the replacement value of the assets at the time, the RCV does not represent the full value of long lived assets constructed before privatisation. If the RCV were used as the measure of capital stock, then additions to the capital base (at full market price) post privatisation would lead to considerable mis-estimation of changes in productivity performance.

Given this, past studies of the productivity growth of the sector have tended to employ proxies of physical capital invested derived from the modern equivalent asset (MEA) valuations that were available in the regulatory accounts until 2015. We continue with this approach.

[4] Further work could be undertaken on the availability of consistent data on labour and other costs in a future study.

Our physical proxy of invested capital is therefore based on a perpetual inventory method adjustment of the MEA capital stocks reported in the companies' regulatory accounts until 2015. We have attempted to extend this series to 2016 and 2017, however given changes to accountancy practices results from these years should be viewed with a degree of caution. Annex A describes how we have needed to adapt our data series due to changes in accounting practices over the period.

To summarise, the variables and approach used to denote the inputs in Frontier's TFP growth index are:

- **Opex index.** This measures the change in the real value of operating expenditure over time. A combination of deflators was used to reflect the fact that opex is composed of both labour, and other costs.[5] The deflator for labour costs is an index constructed from median earnings.[6] For other costs, we used an index based on the MM22 Producer Price Index (PPI).[7]
- **Capital Index.** This measures the change in capital, as defined by total MEA net book amount, over time. It is calculated using the total net book amount in 2010 as a stock, and then adding the combined water and sewage additions as flow variables. Once deflated by COPI, these stock and flows were used to calculate the annual capital index.

2.2 Technique

This study uses the Tornqvist indexing procedure to combine multiple inputs and outputs. This is a very widely used index in TFP growth studies to measure the productivity of a single firm or business unit over time, or the productivity of different firms at a single point in time. The algebraic specification of the Tornqvist index is shown in the box below. Note that the Tornqvist index measures the *difference* in productivity between two time periods or two firms (denoted by s and t), i.e. the change in productivity, not the absolute level of productivity.

5 Since we have no employment data available in recent years, we have assumed a split of labour costs and other opex based on the latest available data.

6 Sourced from the Annual Survey of Hours and Employment

7 The MM22 index for 'Water Supply' (code K698) was no longer produced by ONS beyond 2013 to our knowledge. The series was continued using a more recent MM22 index for 'Inputs for Water Collection, Treat/Supply' (code MC3U).

Figure 4 The Tornquist TFP Growth Index

$$\ln TFP_{st} = \frac{1}{2}\sum_i (R_{is} + R_{it})(\ln Y_{it} - \ln Y_{is}) - \frac{1}{2}\sum_j (C_{js} + C_{jt})(\ln X_{jt} - \ln X_{js})$$

where:

- there are *i = 1…I* outputs (Y);
- there are *j = 1…J* inputs (X);
- R is the output revenue share for each of the *i* outputs (Y);
- C is the input cost share for each of the *j* inputs (X);
- *s* and *t* are two time periods or firms; and
- ln is the natural logarithm.

Source: Frontier Economics

In constructing the index, the capital and operating inputs need to be weighted appropriately. As illustrated in the box, and following Saal & Parker, this is done for outputs by way of water and sewerage outputs' respective shares in total revenues of the sector, and for inputs, by way of the respective shares of capital and operating costs in total regulated economic costs. We have already explained in Section 2.1 above the basis of our input and output indices. Below we explain how we have identified revenue and input cost shares.

Shares

Cost and output shares are defined as follows:

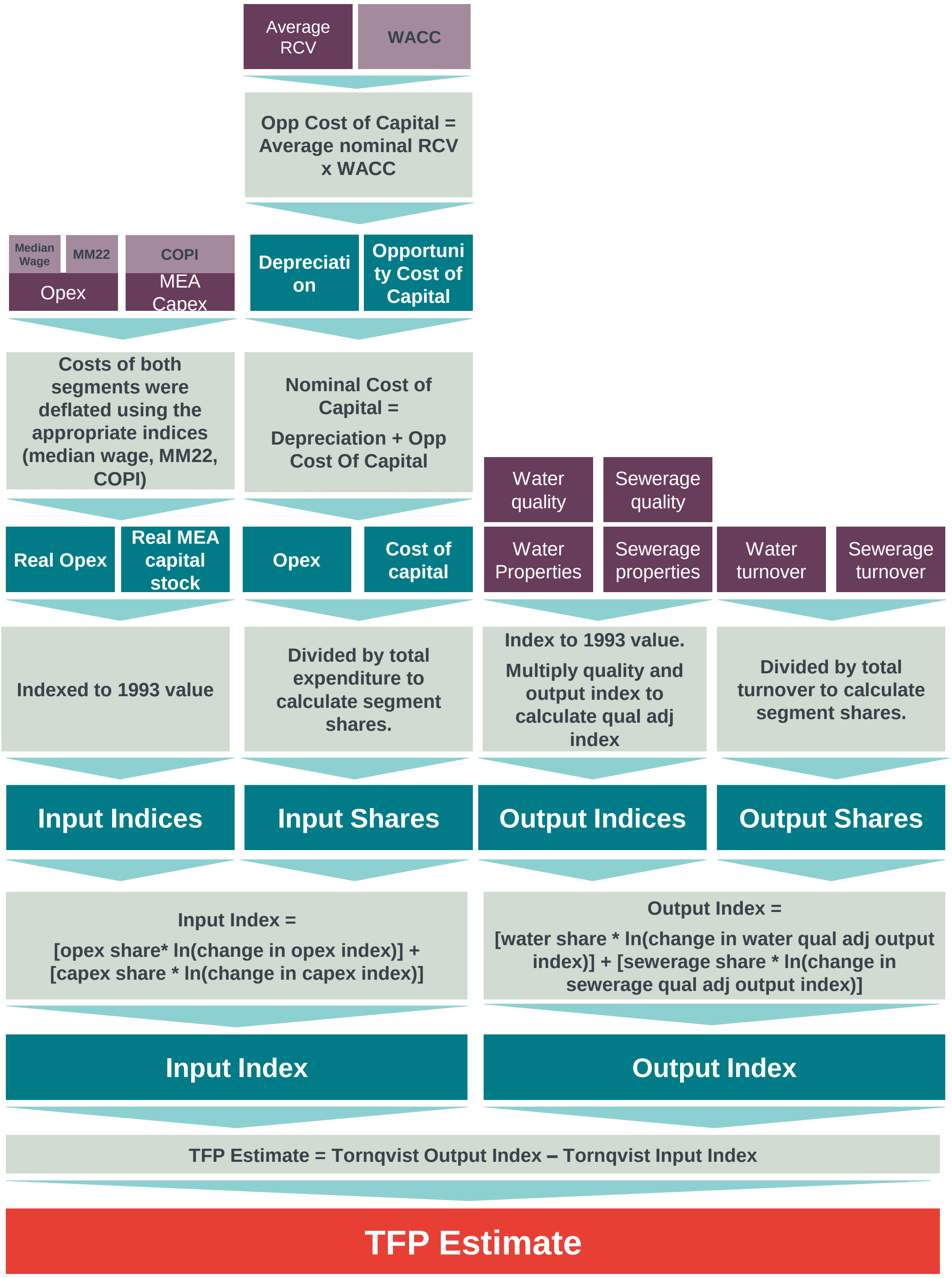
- **Output shares.** These were the percentage of total turnover earned from water and sewerage respectively. As a TFP growth estimate was calculated for every year, the appropriate shares to use for each calculation were the shares for the specific year and the previous one. For example, the TFP growth estimate for 2006 illustrates whether productivity in 2006 had risen or fallen from the level in 2005, the revenue shares required for this estimate were an average of those from 2005 and 2006.
- **Input shares**. These were based on proportion of expenditure related to operating and capital costs. Operating costs was simply operating expenditure sourced from regulatory accounts and the basis for capital costs can be thought of as the 'consumption of capital inputs', which is reflected by the sum of depreciation charges[8] and a return on the capital stock to investor. The approach broadly reflects the implicit value of the invested capital stock allowed for by society via the regulatory determination.

8 More specifically: the sum of infrastructure renewal charges and current cost depreciation charges, where current cost depreciation is the accounting definition that is most consistent with the economic concept of depreciation

  - In calculating the return to the investor on invested capital for the purposes of input shares we have used here the Weighted Average Cost of Capital (WACC) allowed for by Ofwat in each price determination. As this is an ex ante assessment of the WACC, further work could be undertaken to appraise whether an ex post measure of outturn WACC could be developed so as to capture any divergence between Ofwat's allowance and actual financing costs.

- Figure 5 below is a descriptive flow chart of the model used to calculate TFP growth.

Figure 5 Detailed Flow Chart showing the steps taken to derive the Tornquist index



Source: Frontier Economics

2.3 Measurement of quality of service

Improvements in quality have been an important driver of expenditure in the water sector and it is important to capture quality in our TFP growth estimates. A wide range of potential measures of quality exist (although many of these are not available over the entire period of analysis) as does a wide range of potential ways in which quality could be captured. In this section we provide a review of the issues that arise.

2.3.1 Quality of service dimensions

The quality of water and wastewater services is comprised of a number of different elements. These include:

- the safety, colour, odour and taste of drinking water;
- the reliability of services and security of supplies;
- the frequency of sewer flooding;
- the environmental impact of the industry on flows and water quality in rivers, bathing waters and on wildlife through its abstractions of raw water and sewage / effluent discharges;
- leakage rates from pipes; and
- the speed and responsiveness of customer services.

In the early days after privatisation, a major focus of the industry was on meeting European and national water quality and environmental objectives. Major directives such as the Urban Waste Water Treatment Directive (UWWTD),and successive Bathing Water Directives, Drinking Water Directives and other legislation from Europe, as well as the Environment Agency's own River Quality objectives, drove significant investment and improvements in the quality of bathing waters and the cleanliness of beaches, river water cleanliness and quality, and high standards of drinking water quality, including substantial reductions in lead and other harmful substances.

In addition, and alongside these improvements, regulatory incentives were created for companies to deliver improved customer service. The Overall Performance Assessment covered (OPA) a comprehensive set of quality of service dimensions and ran from 2000/2001 to 2009/2010, being thereafter replaced by the Service Incentive Mechanism (SIM) focusing on just two measures: of complaints and customer satisfaction. In the last two price reviews at PR14 and in the current round, PR19, companies are encouraged to set their own measures of performance and are incentivised to meet and surpass these. Common measures selected by Ofwat for PR19 draw on those developed at PR14 and comprise those set out in Figure 6.

Figure 6 Ofwat proposed common measures at PR19

Measures	
Customer measure of experience (C-MeX)	Pollution incidents
Developer measure of experience (D-MeX)	Risk of severe restrictions in a drought
Water quality compliance	Risk of flooding of wastewater systems
Water supply interruptions	Mains bursts (asset health metric 1 - water)
Leakage	Unplanned outage (asset health metric 2 - water)
Per capita consumption	Sewer collapses (asset health metric 3 - wastewater)
Internal sewer flooding	Pollution incidents caused by non-infrastructure (above ground) assets (asset health metric 4 - wastewater)

Source: Ofwat PR19 Draft Methodology, Appendix 2. Outcomes, Table 2.2

We note that not all of these may be relevant as measures to be included in a quality adjustment mechanism for productivity growth purposes. Further discussion of appropriate measures is found in section 2.3.2.

- Some measures may indicate performance that would be captured in the efficiency of delivering the base service captured in the output index, for instance, those relating to asset health and per capita consumption.
- Some relating to survey based customer satisfaction scores may be influenced by a number of factors and it may be difficult to claim they reflect improved service beyond expectations of the base service.
- Leakage may be considered a reasonable measure of quality of service for productivity quality adjustment given that customer research suggests customers place importance on its reduction, however, to the extent that reducing leakage also helps to deliver the base service more efficiently it is not clear that it is appropriate to include as an indicator of quality for the purpose of productivity growth assessments – this could be explored in future development of the approach adopted here.

When considering how to allow for quality in productivity growth assessments, there are a number of different approaches to measurement. This is discussed next.

2.3.2 Developing a measure of quality improvement

There are three broad approaches that might be contemplated.

Monitoring compliance against standards

The premise for this approach is as follows. WoCs and WaSCs are obliged to meet a wide range of water and sewerage quality standards that regulate the quality of drinking water, the impact of the industry on raw water supplies, river and bathing quality. The industry's level of compliance with these tests over time can be taken as a measure of whether the quality of the output of the industry has been improving or declining.

An advantage of this approach is that where standards have been a significant driver of expenditure, this may enable a straightforward way of capturing the main elements of quality that impact on productivity growth estimates. As standards will have been monitored, data could be more readily available.

However, a standards based approach can face a number of problems:

- If standards increase above and beyond the minimum level of compliance over the period, tracking the rate of compliance will understate underlying improvements in quality.
- There may be some standards which vary by individual WoC and WaSC rendering interpretation of compliance rates difficult.
- It is only appropriate for those dimensions of quality that are regulated by a requirement to adhere to specified standards – this might exclude important dimensions of quality that are valued by customers such as supply interruptions, sewer flooding, taste and odour of drinking water, and which may also have attracted expenditure by companies.

Measuring the absolute level of performance for a set of representative quality measures.

An alternative approach involves measuring the absolute level of performance for a set of representative of quality measures.

There are a number of in principle advantages of this approach.

- It avoids having to match the changes in standards with the industry's performance against these standards.
- It is a more useful measure of performance than a simple pass/fail test (as in compliance data).
- It can in principle capture more dimensions of quality.

However, this approach creates potentially onerous data demands, in respect of the availability and consistency of data on a basket of measures both across time and across companies. This might reflect changing regulatory reporting requirements and/or incentives and different company service priorities.

In addition measures may not be closely matched to expenditure or to customer valuation, depending on how they are defined. This may lead to a risk that the measures, if used directly, lead to an arbitrary over- or under-statement of TFP growth.

Using an expenditure based approach

This approach involves assuming that the capital (and related operating) expenditure is a proxy for the social value of quality improvements. Where quality expenditure has been subject to customer engagement and/or regulatory scrutiny e.g. cost benefit analysis, this may not be an unreasonable assumption.

However, the approach does not directly measure the volume of quality improvements or the value placed on them by customers. In addition, where only a proportion of costs could be identified as attributable to service, for instance only capex, or where there are joint costs with the base service, there are potentially challenging cost allocation issues and a risk that not all quality related expenditure is captured. This could lead to an understatement of the effect of quality on TFP growth.

2.3.3 Incorporating a quality measure into Tornqvist TFP growth estimates

Once a measure of quality has been developed, it is necessary to include it in the measurement of TFP growth. Three broad approaches can be considered.

- **Adjusting outputs.** The raw outputs in the economic model (i.e. number of customers connected to water and sewerage services) can be adjusted by an index to reflect changes in the quality of drinking water and level of sewage treatment (these could be derived by either of the first two methods above).
    - Given the quality index generally rises over time, this would have the effect of increasing the number of customers served for a given level of (unadjusted) inputs used to provide water and sewerage services.
    - Where an expenditure approach has been used as the basis of the quality index, this assumes output growth equals input growth for quality.
- **Adjusting inputs**. An alternative approach would be for the quantity/costs of quality specific inputs to be used to adjust inputs. This could be by way of creating an input adjustment index, or more simply by subtracting quality costs from the inputs. In other words the higher standard of service is proxied by the additional quantity/costs of inputs required to deliver it.
    - The impact on the overall productivity growth index would be the same as if the output index were adjusted by an index representing quality expenditure, albeit that the evolution of the underlying input and output series would then be different.
- **A combination of the two approaches**. Adjustments for inputs and outputs, if some measures of quality are expenditure based and others output based. The additional complexity may be a drawback, but this more complex approach may provide a way of handling a potential rich range of quality measures with different properties and features.

2.3.4 Approach adopted in report

As in other dimensions, this report adopts the Saal & Parker approach. The Saal & Parker method uses compliance based measures of quality for water and an output measure for wastewater. These measures are used to develop an adjustment to the output index. The measures were selected by Saal & Parker to reflect the focus of capital investment in quality in the ten years after privatisation, which was the relevant period for their original study. The key drivers were to meet higher standards of drinking water quality, including lead removal, and of bathing and river water quality, driven by a number of European and UK regulations. The measures captured well the focus of the sector over the period of analysis.

We were not able to directly extend the wastewater variable used in Saal & Parker, which was a composite of river water quality and bathing water quality. However in discussion with the Environment Agency we have selected a measure that broadly captures the river water quality dimension represented in the Saal & Parker measure, thereby ensuring a reasonable degree of consistency (see Annex A for further details).

This approach consists of adjusting water and sewerage outputs using the following measures:

- **Water**: average compliance up to 2011 (WoCs) and 2014 (WaSCs), Mean Zonal Compliance (MZC) onwards.[9]
- **Sewerage**: a composite index of Ammoniacal Nitrate and BOD in river water.

Adjustments for quality present significant challenges. We are comfortable that the approach to quality adopted in this study is fit for purpose and reasonable. We consider that the approach is conservative but if time and data constraints were lifted it would be possible to develop alternatives that are potentially more accurate. We describe these alternatives below.

Water quality measure

For the purposes of extending the analysis since 2000 we consider that the water measure has remained broadly relevant as a key measure, at least for the first decade of the period.

- Investment in drinking water quality improvements reduced overall in this period, and there has been a shift from quality enhancement to maintenance expenditure, but drinking water quality remains the key driver of service quality enhancement expenditure in the water service.
- There has been some increase in allowed expenditure on service and a new focus on resilience and increased supply security in recent years, which is not captured by MZC. MZC may therefore be underestimating water quality output growth in recent years (and in the future). This feature of the data may

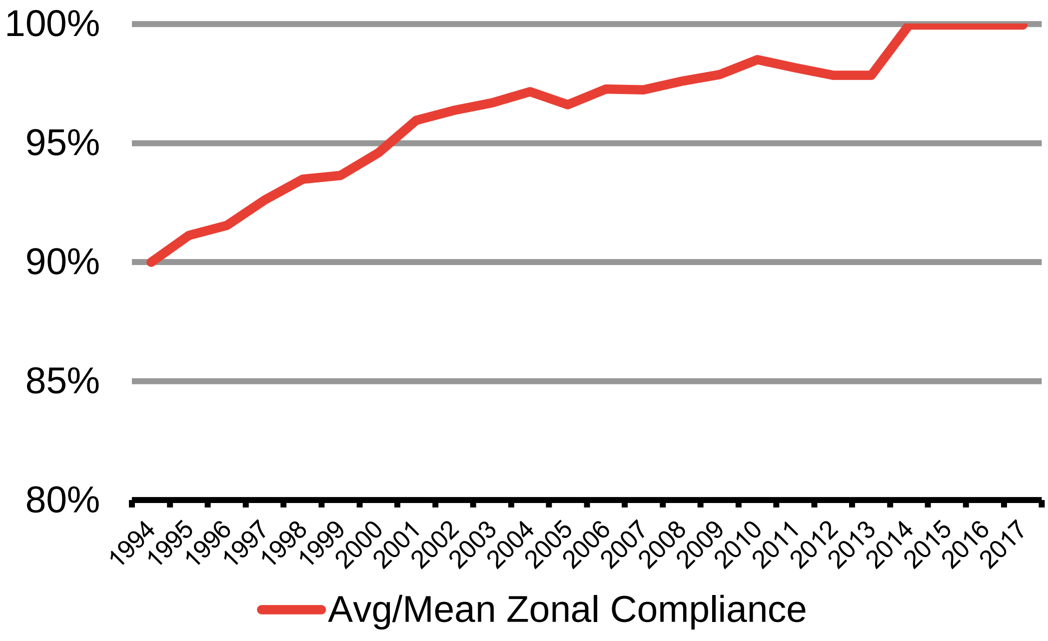
[9] Average compliance (across zones) is defined as the average proportion of supply zones compliant with standards across a number of parameters. Over the course of a year, the DWI carries out a number of tests in each water supply zone. If any of these tests in a zone fail on a particular parameter the whole zone is marked as failing on that parameter for the whole year, i.e. there may be many hundreds of tests conducted and even a single failure is sufficient for the zone to fail. MZC is based on the same DWI data, but for each company MZC is simply the number of tests passed divided by the total number tests. Since the vast majority of tests are passed, MZC has been “high” in all years and while some increase has been observed over time, this is small and in our view does not reflect well the expenditure and effort that has gone into improving water quality. Average compliance across zones is therefore a “tougher” measure of quality, which produces a lower measure than MZC for any given set of data, and which shows a more substantial increase over time. In our view, Average compliance provides a better proxy for water quality improvement over the relevant period, more reflective of expenditure and effort. For a fuller discussion of potential refinements around the measurement of quality, refer to Section 5.

be characterised as conservative (i.e. more likely to underestimate TFP growth than overestimate).

- We were only able to collect data on Average Compliance up to 2011 (WoCs) or 2014 (WaSCs). We therefore extend this series to 2017 using Mean Zonal Compliance. To mitigate some of the effects of this we used a smoothed index which was an average.

The chart below illustrates the growth in drinking water quality as measured by the average compliance/mean zonal compliance.

Figure 7 Drinking water quality, 1994-2017



Source: Frontier Economics

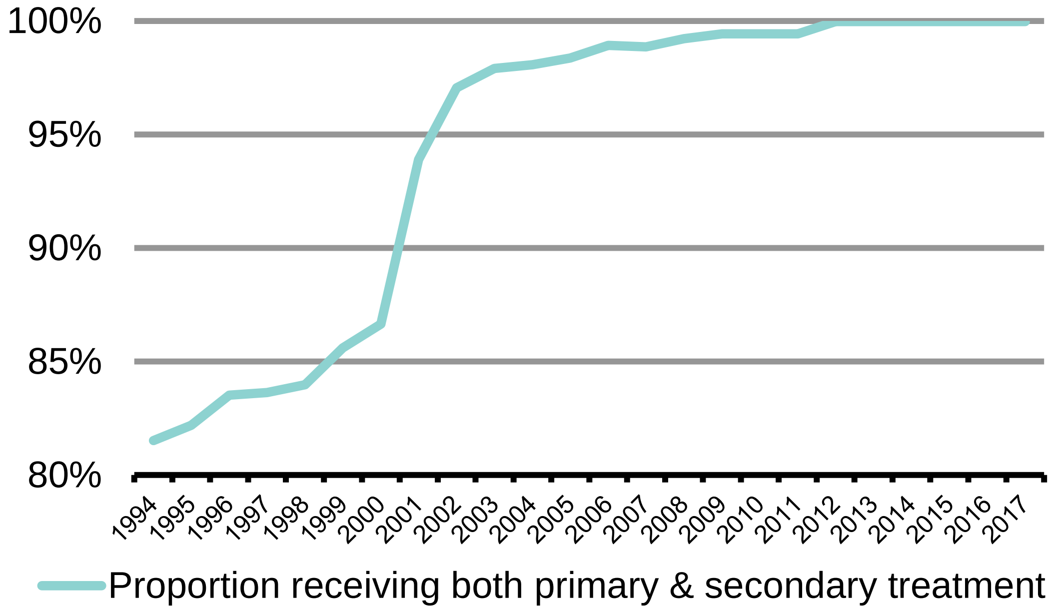
Sewerage quality measure

In choosing the wastewater quality measure to adjust sewerage outputs, we considered a wide range of possible alternatives.

We considered a measure of population connected to primary and secondary treatment but as shown below in Figure 8 the problem with this approach is that, while it may capture well the increases in quality in the 1990s and early 2000s, it then flattens out after 2003. Since then there has also been the addition of tertiary treatment. These further incremental improvements are therefore not captured in our measure. The effect of this would be to apply no quality adjustment for this dimension for more recent years in the period of analysis.

Although expenditure on river and bathing water quality improvements has reduced since the 1990s it still remains responsible for approximately 25% of quality capital expenditure in wastewater, and there have continued to be environmental improvements in water bodies. We therefore considered this unsatisfactory.

Figure 8 Proportion of population receiving both primary & secondary sewerage treatment, 1994-2017

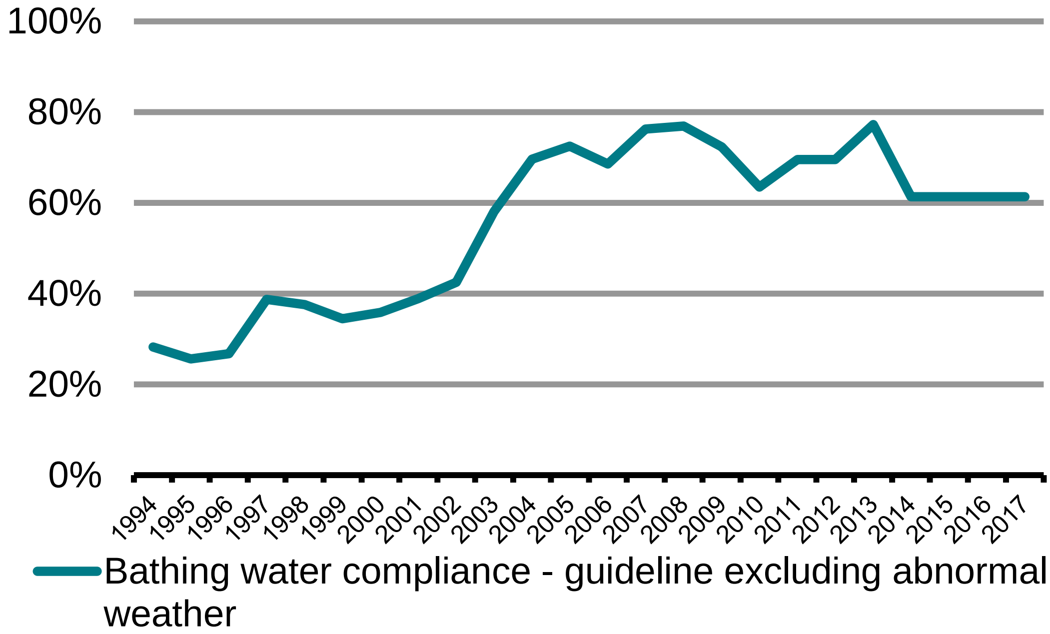


Source: Frontier Economics

Note: We base this series on effluent load up to 2005 and then domestic load from there onwards. Consistent data on effluent was not available after this year.

We also considered including a bathing water metric, but the rapid increase in quality in the 1990s and up to 2003 (illustrated below in Figure 9) revealed by this measure was considered implausibly large, and inconsistent with the cost reflectivity.

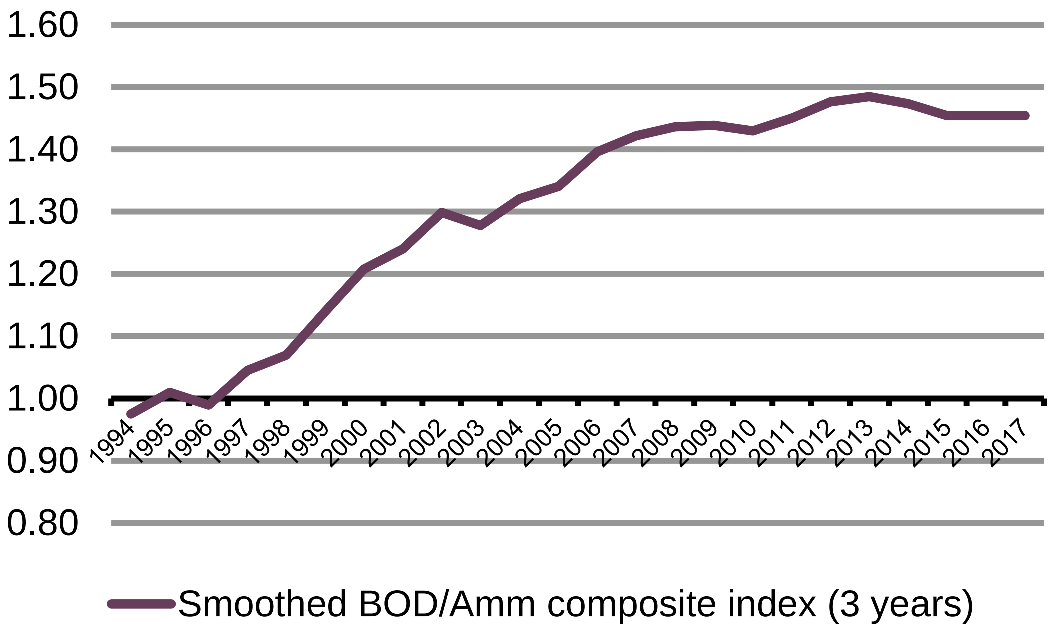
Figure 9 Bathing water compliance (excl. abnormal weather), 1994-2017



Source: Frontier Economics

The river water quality measure we ultimately decided to use, suggests a continued though slower improvement in quality from 2004 up to 2013[10] and significant growth over the whole period (see Figure 11 to Figure 13 below). These provide a pattern of improvement in that period more consistent with the continued expenditure on quality improvements.

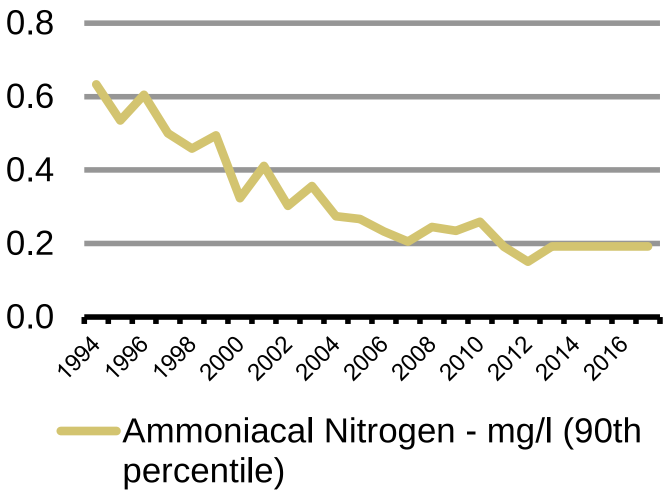
Figure 10 River water quality index, 1994-2017



Source: Frontier Economics

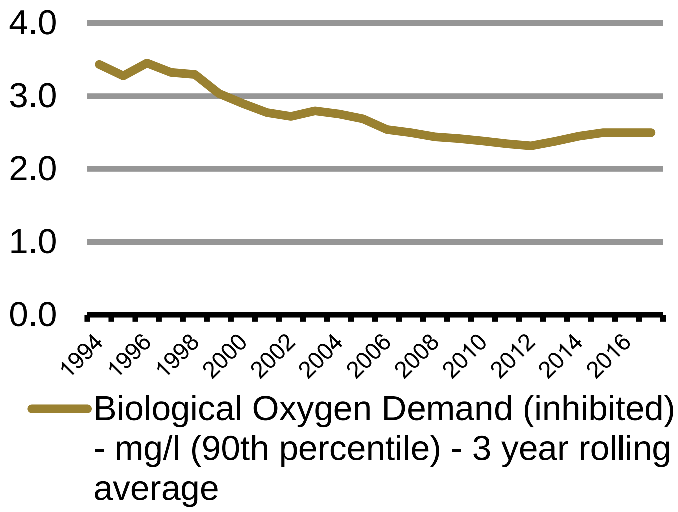
Note: Based on equal weighting to Ammonical Nitrogen and Biological Oxygen Demand

Figure 11. Ammonical nitrogen, 1994-2017



Source: Frontier Economics

Figure 12. Biological Oxygen Demand, 1994-2017



Source: Frontier Economics

10 Note that data for this series have not been available post 2013. In order to facilitate measurement to the end of the period, we have extended the series using the 2013 level. We consider this a conservative assumption.

We consider that this measure provides a plausible and on balance relatively conservative approach to wastewater quality measurement. It is less conservative than the measure of population served by primary and secondary treatment between 2000 and 2013, but more conservative than adding in bathing waters (for earlier years). We note that it does not capture the growth in wastewater service quality along new dimensions that have become increasingly important in recent years (see next section). This means that especially since 2013 the measure is likely to underestimate productivity growth.

We turn next to an overview of alternative measures for quality that we have considered but were outside the scope of our study for a detailed and robust analysis in the time period.

2.3.5 Data availability to support future work

It is helpful to consider what further work might be conducted. This is inevitably dependent on the availability of relevant and consistent data over a long period of time. Our appraisal of potential alternative approaches to quality adjustment has focussed on three priorities:

- identifying drivers of quality that are significant in expenditure terms and are also of importance to customers; and
- focussing on measures relevant in the period since 2005, and reflecting the focus of regulatory and company incentives.

Our appraisal of future options has also assumed that more time intensive methods, involving significant data collection and cleansing, become feasible.

We have included in our review the relevant common measures to be set by Ofwat for incentivisation at PR14 as discussed earlier. Following discussion with the industry, these were considered to also broadly cover the key expected areas of company expenditure.

Our findings on potential future alternatives are presented in the table below. This table is unlikely to represent all potential future approaches to measuring quality, but it should provide a strong indication of the potential direction for future work.

We discuss further in section 5 possible ways of extending our current analysis. We believe a number of sensitivity assessments are worth exploring, collecting and using data on a wider range of service measures and trialling different weighting mechanisms within the Tornqvist index. Prime candidates would be leakage, supply interruptions, and sewer flooding as well as an expenditure based approach. We also discuss techniques that rely on cost function estimation.

Figure 13 Quality measures examined for the report

Source/type	Metric	Has it been included?	If not, why? If so, are there remaining data concerns?
Compliance based, Saal & Parker (2001)	Average / Mean zonal compliance	Yes	In the future this measure might be weighted with new measures capturing other service attributes that are now important to customers and as cost drivers
	Population receiving primary and secondary treatment	No	Compliance is near 100% after 2005, and this does not practically reflect investment in quality after this period or measured improvements in river water quality.
Outcome based, Company level measures	Leakage	No	Although leakage is an important measure of quality, as reducing leakage also helps to deliver the base service more efficiently, it is not clear that it is appropriate to use it for the purpose of productivity growth assessments. This could be explored in future development of the approach.
	Unplanned supply interruptions > 3, > 6, >12 and >24 hours	No	The measurement and incentivisation of interruptions has changed over time – deriving a consistent measure for this study was beyond scope
	Low pressure	No	Compliance is near 100% after 2005, and this does not practically reflect investment in quality after this period
	Internal sewer flooding	No	Volatility is due to weather events outside of the control of water companies
Outcome based, EA	Ammoniacal nitrogen	Yes	No data after 2013 as the Harmonised Monitoring Scheme was discontinued, therefore the 2013 level was conservatively extrapolated as a constant level
	Biological oxygen demand	Yes	
	Bathing water compliance	No	Compliance is near 100% after 2005, and this does not practically reflect investment in quality after this period
Expenditure based, industry data	Enhancement expenditure	No	We believe this is a promising approach that could serve well in tandem with an outputs based approach, but the project scope and time constraints did not permit the additional considerable task involved to collate and test appropriate data sets.

Source: Frontier Economics

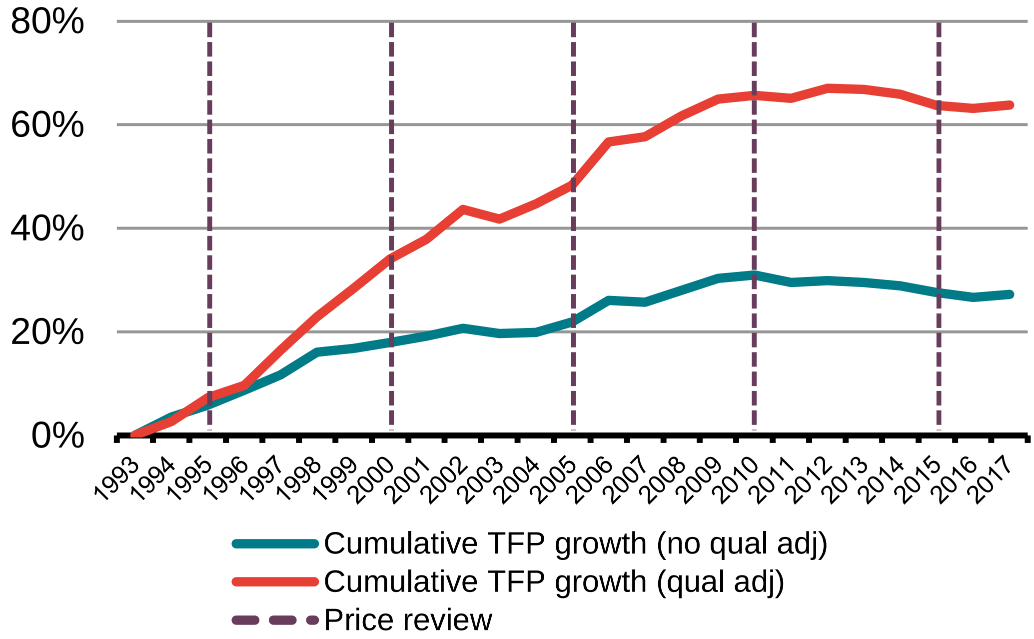
2.4 Results

2.4.1 TFP growth estimates for the water and sewerage industry

Below we present a summary of the results of our analysis. The average rate of quality adjusted productivity growth has been 2.1% since privatisation, while an excessively conservative estimate of quality unadjusted productivity growth suggests an average annual rate of 1.0% since privatisation. Figure 15 suggests that while productivity continued to grow the growth rate has been falling since the mid to late 1990s. Productivity growth appears to have picked up in 2016. However, the years 2016 and 2017 are problematic in terms of data consistency due to changes in reporting, so should be treated with caution.

The estimated impact of quality on TFP growth is shown to have been substantial up to the early 2000s, but the more muted impact since then is likely to be partly due to the conservative nature of the quality measures adopted as discussed earlier.

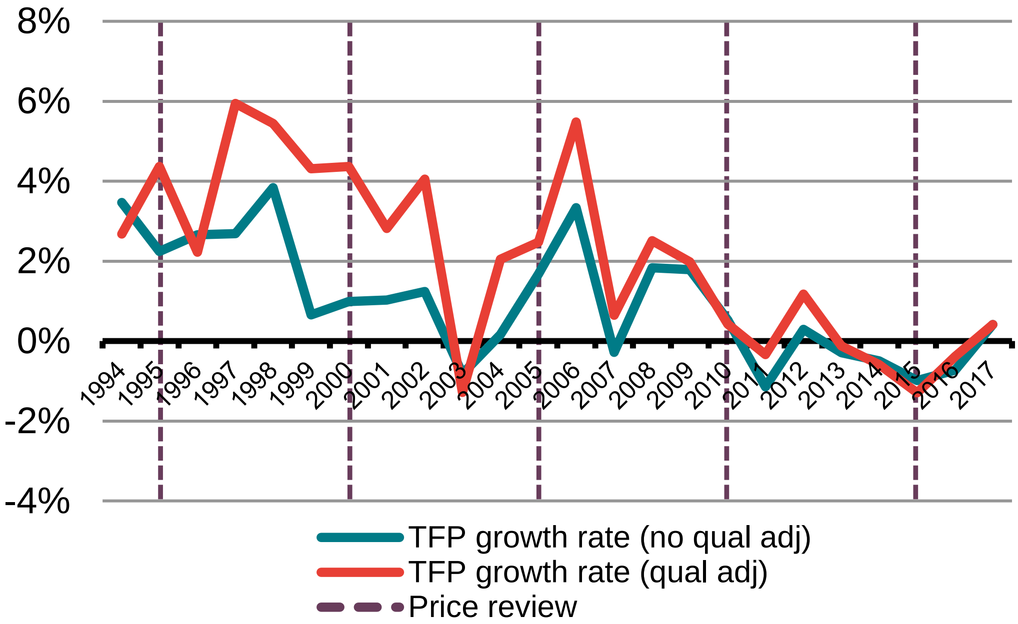
Figure 14 Cumulative TFP growth, 1993-2017



Source: Frontier Economics

Note: Relative to TFP in 1993

Figure 15 TFP growth estimates for England Water & Sewerage Industry, 1994-2017

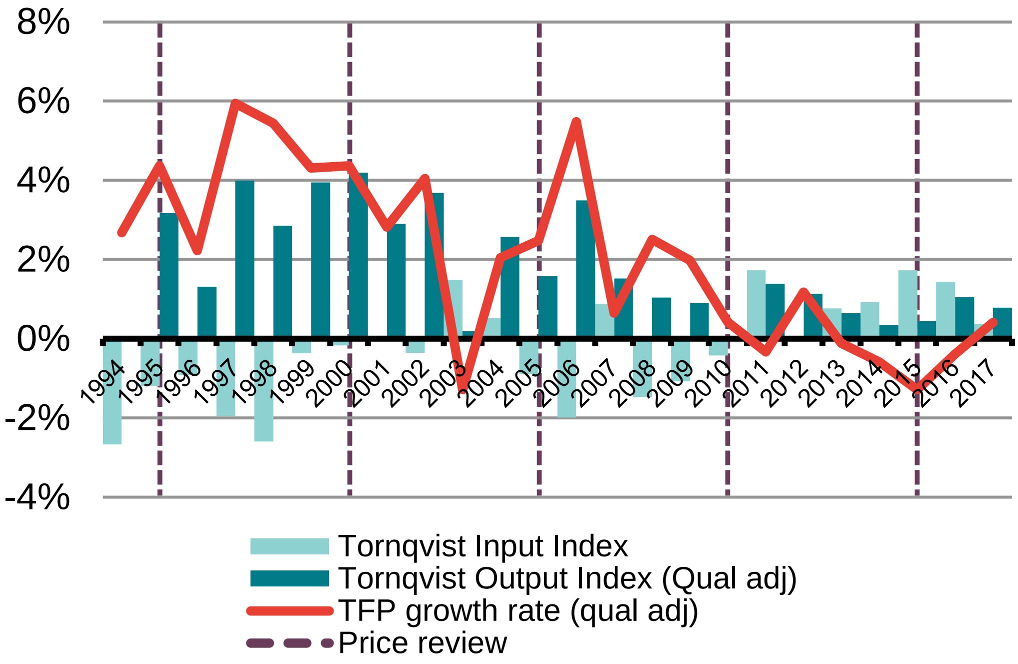


Source: Frontier Economics

Figure 16 below identifies how productivity growth has been driven by the trends in output and input growth. This appears to suggest that productivity growth was driven both by investment to increase drinking water quality standards and to meet more stringent environmental regulations to reduce the impact of waste water discharges on the aquatic environment. Also, the ‘privatisation’ effect (and/or the impact of adopting a high powered incentive regulation system) prompted companies to become more efficient reducing their inputs, particularly opex.

However from 2006 on, the growth in outputs shrunk significantly (so that productivity growth remained positive but slowed). From 2012 onwards input usage increases significantly outweighed modest increases in output, to deliver a falling productivity growth trend overall.

Figure 16 TFP growth estimates for England Water Industry 1994-2017 quality adjusted



Source: Frontier Economics

Figure 17 below summarises the productivity growth estimates over different subsets of years over the whole period since privatisation.

Figure 17 Annual TFP growth estimates over various periods

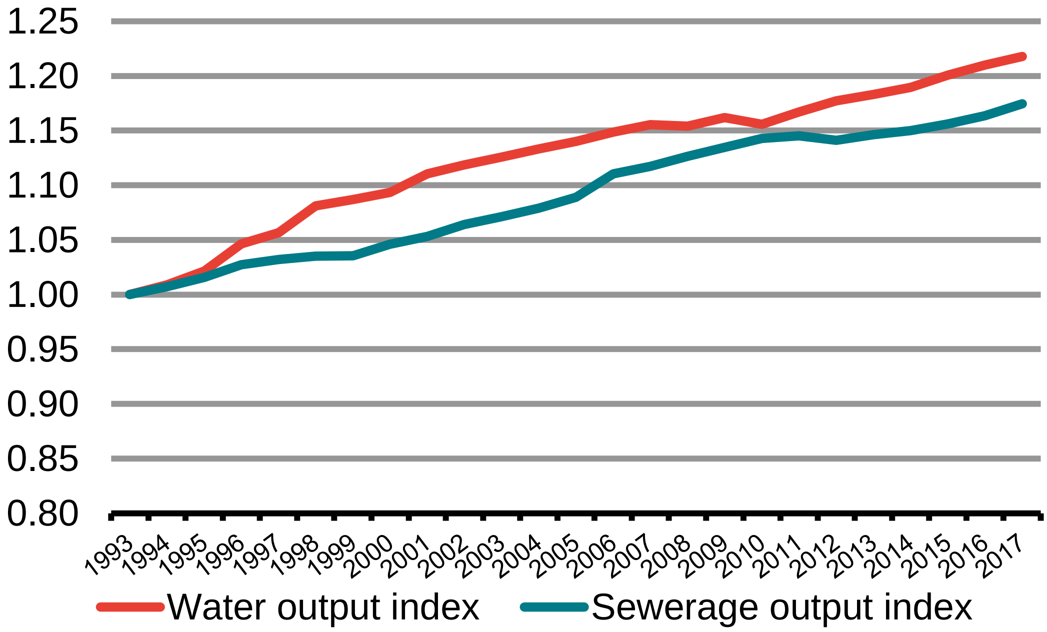
Period	TFP average growth (no qual adj)	TFP average growth (qual adj)
1994-1995	2.9%	3.5%
1996-2000	2.2%	4.5%
2001-2005	0.7%	2.0%
2006-2010	1.4%	2.2%
2011-2015	-0.5%	-0.2%
2016-2017	-0.2%	0.0%
1994-2008 Business Cycle 1	1.6%	3.2%
2009-2017 Business Cycle 2	-0.1%	0.1%
1994-2017	1.0%	2.1%

Source: Frontier Economics

2.4.2 The evolution of outputs and inputs over time

As noted above output growth as measured here, in terms of numbers of connections, has increased only slowly over the period.

Figure 18 Water and Sewerage Output indices

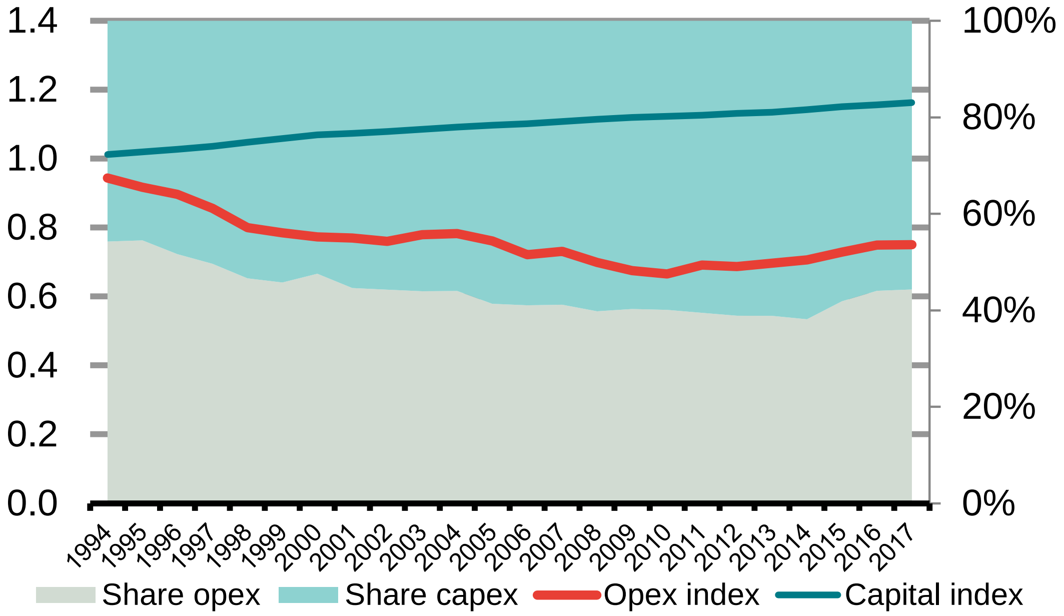


Source: Frontier Economics

In addition to the growth of outputs over time, the productivity estimates are determined by changes in input usage. Figure 19 illustrates the evolution of inputs since 1992. There are two key trends that explain the movement in the input growth index in this period:

- The growth of inputs (in real terms). The MEA based measure of the capital stock has grown at a relatively steady rate since privatisation. On the other hand, our measure of real operating expenditures (labour and other costs) has decreased during the 1990s to a level of approximately 70% of the opex in 1991 in real terms. This level has stayed broadly constant since then, despite a slight upward trend since approximately 2010.
- The share of inputs in total costs. At privatisation, opex represented about two thirds of all costs. Since 2000, the share of capital in total costs has been at least 50%. We note that the reported fall in the capital cost share post 2015, is likely to result from regulatory reporting changes, and would merit further investigation.

Figure 19 Evolution on inputs over time, 1994-2017



Source: Frontier Economics

The trends shown in Figure 19 provide an additional explanation for the high productivity growth during the period since privatisation until 2000. In addition to output growth, productivity growth was driven by input decrease, particularly of opex. Since 2000, opex levels have been broadly stable, with a temporary decrease in the period between 2008 and 2011 and recovery between 2011 and 2015. These changes in opex growth had a direct impact on the input index and, consequently, the industry's productivity growth.

2.4.3 The contribution of quality enhancement to TFP growth

The charts above illustrate the significance of the growth in the output index as a key driver in water and sewerage productivity growth. Here we review the contribution to that growth derived from the specific incorporation of our quality adjustment variables, reflecting the improvement in a range of quality dimensions of the water and sewerage service.

Using the quality measures used in Saal & Parker we find a considerable increase in the productivity growth estimate up to 2004. In particular, the average annual TFP growth between 1992 and 2004 was approximately 2% without the quality adjustment and 3% with the quality adjustment. In other words, quality improvements result in a productivity growth increase of 1 percentage point per annum. The more muted impact since then is likely to be partly due to the conservative nature of the quality measures adopted as discussed earlier. We recommend further work to improve the measurement of quality impacts in the future (see Section 5).

3 TFP GROWTH ANALYSIS OF COMPARATOR SECTORS

In this section we consider evidence on productivity growth in other sectors of the economy, drawing on information sourced from the EU KLEMS database.

Evidence on productivity growth achieved by relevant comparator sectors of the economy is used to cross-check our estimates in Section 2 above for the water and sewerage sector. Our choice of comparator sectors is informed by:

- the extent to which the comparator sectors carry out comparable activities to water and sewerage businesses;
- the extent to which the comparator sectors have a similar mix of opex and capital in the production process to water and sewerage businesses;
- the extent to which the comparator sectors have experienced the similar economic and/or regulatory conditions facing the water and sewerage business over the relevant period; and
- the extent to which the sectors were considered as relevant comparators for large regulated infrastructure utility businesses in previous studies commissioned by Ofgem, Ofwat, the ORR, and Water UK, which we discuss in Annex C (i.e. regulatory precedent).

We note that while we have sought to find the most suitable comparator sectors against which to compare the productivity growth of the water and sewerage businesses, it is of course the case that none of our short-listed industries undertake exactly the same activities. Furthermore, there are cases where comparator sectors meet one or more, but not all, of the criteria above. Hence the indirect comparisons of productivity we make here against other sectors of the economy need to be interpreted with caution. Notwithstanding this caveat, we consider the results presented to be an informative comparison.

The remainder of this section is structured as follows.

- In Section 3.1 we outline the comparator sectors from the EU KLEMS database that have been short-listed for comparison with the water and sewerage businesses.
- In 3.2 we present a comparative summary of the average annual rates of productivity growth achieved by the water and sewerage businesses (from Section 2above), the comparator sectors from the EU KLEMS data.
- In Section 3.3 we draw inferences on the extent to which the water and sewerage businesses have outperformed or underperformed the comparator sectors from the EU KLEMS data, both pre- and post- privatisation and both pre- and post-GFC.
- In Section 3.4 we outline our conclusions.

3.1 Relevant comparator sectors

Our own appraisal of the criteria presented above and our review of the relevant precedent in the sections (Annex C) suggests that there is significant overlap in the comparator sectors considered in the relevant studies commissioned by Ofgem, Ofwat, ORR and Water UK.

Our consolidated list of sectors from the EU KLEMS data to be considered in this study is summarised below[11].

- Electricity, gas & water supply;
- Manufacture of Chemicals & Chemical Products;
- Manufacture of Electrical & Optical Equipment;
- Manufacture of Transport Equipment;
- Construction;
- Sale, Maintenance & Repair of Motor Vehicles/Motorcycles; Retail Sale of Fuel;
- Renting of Machinery and Equipment and other Business Activities.
- Finance, Insurance, Real Estate and Business Services;
- Financial Intermediation;
- Transport & Storage; and
- Post and Telecommunications.

We present the results of the productivity estimates from EU KLEMS compared to both the quality adjusted and quality unadjusted results from our study. However, in our view it is more appropriate to compare the EU KLEMS series to the quality adjusted measures from our study. This is because the real output measures to which the EU KLEMS methodology is applied are derived in a manner that takes account of the effect of quality changes on prices.[12]

3.2 Comparison of water and sewerage TFP growth with selected sectors in the EU KLEMS

In order to comment on the extent to which the water and sewerage businesses, on the basis of our analysis in Section 2, have outperformed or underperformed the comparator sectors from the EU KLEMS data we compare average annual

[11] As we do not consider it possible to achieve an accurate and robust mapping of the costs of water and sewerage businesses with sectors in the EU KLEMS dataset, we do not propose to derive a 'composite benchmark' considered in some of the studies reviewed in (Annex C).

[12] See for example the ONS Productivity Handbook, Chapter 12, page 169, which describes the measures derived by the EU KLEMS method as reflecting differences in quality over time and between countries, albeit that the exact approach to accounting for quality will vary from sector to sector.

rates of productivity growth over complete business cycles, to smooth out potential cyclical peaks and troughs[13].

With regards to the EU KLEMS data, we consider TFP value added (VA) growth estimates[14] covering the following periods[15]:

- **Pre-privatisation**: The first full business cycle covering the period immediately prior to privatisation of the water and sewerage businesses is 1982 – 1991[16]:
- **Post-privatisation**: including the following two periods.
  - **Pre-GFC**: the first full business cycle covering the period immediately after the privatisation of the water and sewerage businesses, pre-GFC is 1994 – 2008.
  - **Post-GFC**: We also compare average annual rates of growth in the period from 2009 onwards, bearing in mind that as this period covers an incomplete business cycle, including a period of economic downturn since 2008, we would expect productivity growth to be lower in this latest period than in the complete business cycles above.

Similarly, owing to the more limited coverage of our study in Section 2 over the period 1993 to 2016, we provide a mapping against the periods above as follows.

- **Pre-privatisation**: we note that our study in Section 2 does not cover this period.
- **Post-privatisation**: including the following two periods.
  - **Pre-GFC**: Our study in Section 2 covers the first full business cycle covering the period immediately after the privatisation of the water and sewerage businesses, pre-GFC (1994 – 2008).
  - **Post-GFC**: Our study in Section 2 covers the incomplete post-GFC downturn period (2009 – 2015), where productivity growth is likely to be low.

Figure 20[17] below presents a comparison of average annual productivity growth rates achieved by:

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13 Productivity is commonly recognised to be a highly cyclical variable, which varies across phases of the business cycle and across business cycles. When comparing average productivity growth across sectors over periods of time, it is important for the analysis to cover full business cycles to avoid introducing a bias in the productivity estimates by periods of unusually high or unusually low growth (from shorter periods around peaks or troughs within a business cycle, for example). TFP growth comparisons between our estimates and the EU KLEMS comparators are, therefore, made over a complete business cycle to avoid misrepresenting the impact of recessionary or growth periods.

14 We have derived TFP value added growth estimates from the EU KLEMS datasets published in 2017 and 2012. It is not possible to combine the two publications. This is because the 2017 iteration has updated some of the raw data, making the two publications inconsistent. Updates include changing the capital stock figure source to Eurostat, and amending the geometric depreciation rates. .Our estimates in Figure 20 are drawn from the 2012 dataset for years up to 2008 and from the 2017 dataset for the years from 2009 onwards.

15 Which were determined by observing trends in UK GDP growth and TFP VA growth of all sectors of the economy over time.

16 We do not consider the EU KLEMS data prior to 1982 as these older estimates are likely to be less relevant to our study.

- the water and sewerage businesses (Section 2.4.1 TFP growth estimates for the water and sewerage industry); and
- comparator sectors of the economy from the EU KLEMS database.

[17] The numbers in this table are derived from TFP value added (VA) estimates reported in EU KLEMS. It is worth noting that the value added TFP growth figures are larger than the output growth TFP figures by construct. Value added figures do not include intermediate outputs. Growth output figures from EU KLEMS would be lower. TFP GO growth figures have not been calculated in this report, due partially to data constraints in the 2017 EU KLEMS data.

Figure 20 Average annual TFP growth

Industry	1982-1991	1994-2008	2009 - 2015
Water and sewerage businesses (Frontier Economics estimate) – quality adjusted	n/a	3.21%	0.14%
Water and sewerage businesses (Frontier Economics estimate) – quality unadjusted	n/a	1.6%	-0.1%
Comparator sectors:			
Chemicals And Chemical Products	6.28%	3.90%	-0.07%
Electrical And Optical Equipment	6.06%	2.35%	0.19%
Electricity, Gas And Water Supply	1.80%	0.90%	-3.45%
Construction	3.13%	0.13%	-0.05%
Wholesale And Retail Trade; Repair Of Motor Vehicles And Motorcycles	0.18%	0.30%	0.47%
Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles	3.21%	2.62%	2.84%
Wholesale Trade, Except Of Motor Vehicles And Motorcycles	1.85%	0.31%	0.51%
Retail Trade, Except Of Motor Vehicles And Motorcycles	2.95%	-0.36%	-0.17%
Transport And Storage	2.51%	1.08%	-0.63%
Postal And Courier Activities	0.81%	-0.63%	-0.42%
Telecommunications	-0.44%	7.65%	0.20%
Financial And Insurance Activities	-1.80%	2.04%	-2.72%
Average of comparator sectors	2.21%	1.69%	-0.28%
Average of all sectors **from EU KLEMS data**	0.93%	0.65%	-0.28%

Source: EU KLEMS, and Frontier Economics

3.3 Inferences from evidence on comparator sectors

Inferences from Figure 20 are drawn over the following periods.

- **The period following privatisation (1994 – 2008 and 2009- 2015),** where we can compare our analysis of water and sewerage businesses in Section 2 above with comparator sectors from EU KLEMS.
- **The period prior to privatisation (1982 – 1991)**, where we do not have data on the water and sewerage business from our study in Section 2 as our data starts from 1993 onwards. However, to analyse trends over this period, we compare the average annual rate of productivity growth achieved by the electricity gas and water supply sector relative to all comparator sectors on average, drawing on the EU KLEMS data.

We discuss each of these periods in turn below.

3.3.1 The period following privatisation (1994 – 2008 and 2009-2015)

Pre-GFC (the business cycle 1994 -2008)

The following observations are made from Figure 20 above over the business cycle 1994 -2008.

- Average annual productivity growth achieved by the water and sewerage businesses (3.21% quality- adjusted) was higher than the average annual productivity growth achieved in the comparator sectors short-listed above, on average (1.69%).
- Furthermore, it can be seen that productivity growth achieved by the water and sewerage businesses has outperformed all other comparator sectors with the exception of:
  - the telecommunication sector, which can be explained by the rapid technological progress experienced by this sector over this period, and
  - the chemicals and chemical products sector, which we do not consider to have a particularly comparable input opex and capital mix to the water and sewerage businesses.
- Post-GFC (the downturn period from 2009 – 2015 - incomplete business cycle)

The following observations are made from Figure 20 above over the years 2009 – 2015, which cover an incomplete business cycle following the GFC.

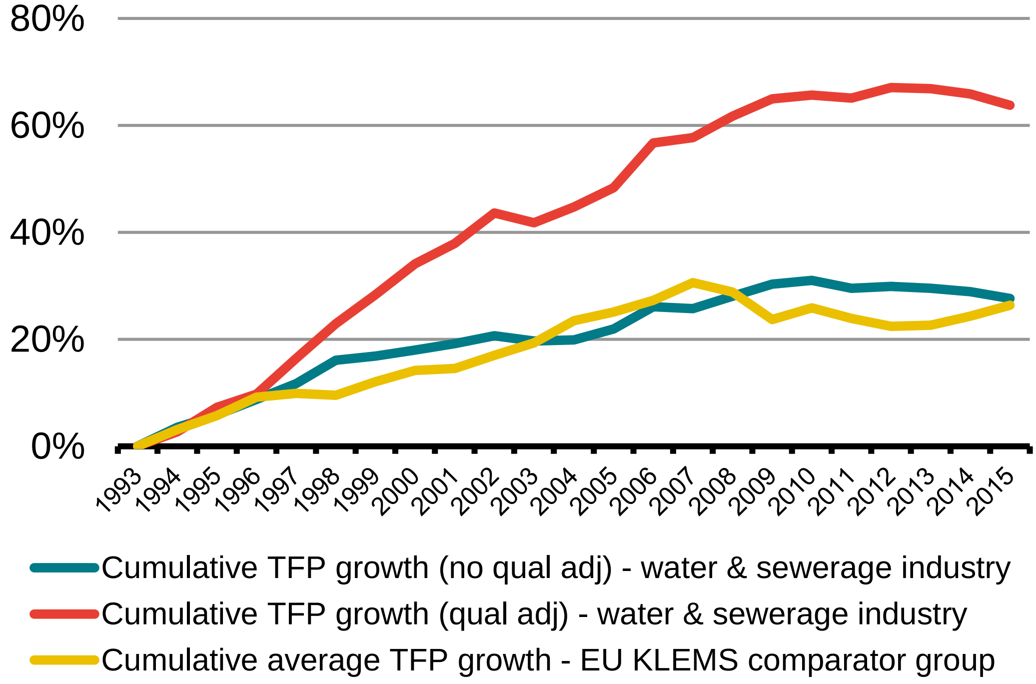
- The UK's productivity growth (-0.28%) and the productivity growth of the comparator sectors have been negative on average (-0.28%), in the post-GFC period.
- The water and sewerage businesses have outperformed (0.14% quality-adjusted) in comparison, achieving modest positive growth post GFC.

- Finally, it can be seen that the water and sewerage businesses have outperformed the growth achieved by the electricity, gas and water supply sector in total, which underperformed all other comparator sectors at -3.45%. Owing to a lack of granular data from EU KLEMS, it is not possible to decompose the EU KLEMS estimates into the three relevant sub-sectors. Given the relative size and value of the gas and electricity sectors, their performance will dominate the results for this composite sector. An appraisal of productivity growth in the energy sector and the extent to which it is captured accurately by the EU KLEMS methodology is beyond the scope of this study. The negative productivity growth in the aggregate electricity, gas and water supply sector may potentially be explained by factors largely unrelated to water, such as the ongoing transition to a low carbon economy which is driving significant expenditure in the energy sector, coupled with wider business cycle effects.

Cumulative growth in TFP over the whole period

Figure 21 compares cumulative TFP growth in the water and sewerage industry with cumulative average growth in the comparator sectors selected from the EU KLEMS database.

Figure 21 Cumulative TFP growth in the Water & Sewerage Industry and the EU KLEMS comparator group



Source: Frontier Economics, EU KLEMS

Quality adjusted cumulative TFP growth in the water and sewerage sector is materially larger than amongst the comparator group, while a highly conservative comparison on a quality unadjusted basis illustrates similar cumulative TFP growth in water and sewerage compared to the comparator group.

3.3.2 The period prior to privatisation (1982 – 1991)

For the business cycle starting prior to privatisation (1982 – 1991), for which we do not have data on productivity growth achieved by the water and sewerage business from our study, we compare the average annual rate of productivity growth achieved by the electricity gas and water supply sector relative to all comparator sectors on average.

It can be seen from Figure 20 that, prior to privatisation, average annual productivity growth achieved by the electricity, gas and water supply sector (1.8%) was lower than the average annual productivity growth achieved by the comparator sectors (2.21%, on average).

3.4 Conclusions from evidence on comparator sectors

Our analysis of productivity growth in comparator sectors suggests that the water and sewerage businesses have outperformed materially those comparators in the decades after privatisation and leading up to the GFC in 2008. Since then, the UK's productivity growth and the productivity growth of comparator sectors has been negative. The water sector has not been immune to this trend, with productivity growth materially slower than in the post privatisation period, but the water and sewerage businesses have nonetheless delivered modest positive productivity growth.

4 LITERATURE REVIEW SUMMARY

Annex B contains our detailed literature review. The review is not meant to be exhaustive, but is instead targeted at those approaches that have the greatest potential for providing a more comprehensive analysis of productivity growth trends in the English water industry.

We have therefore focused on highlighting previous academic application in the UK of several methodologies that are most likely to provide productivity growth estimates that are robust to differences in quality and operational characteristics, and that will deepen the industry's understanding of what factors have contributed to past productivity growth and may do so in the future. Although dated, the Coelli, et al (2003) primer on efficiency and productivity growth measurement published by the World Bank Institute is illustrative of the variety of methods that can be employed to measure and decompose productivity growth in infrastructure industries.

Section 5 of our report provides more detail on our suggestions for future research. However, we emphasise that the chosen papers demonstrate the strong potential of deriving productivity growth estimates from cost and input distance function approaches. These can be estimated with standard panel econometric, DEA, and/or SFA estimation techniques.

We also briefly note the potential to extend TFP growth analysis with the profit decomposition approaches also included in Saal & Parker (2001), as there allow an analysis of how both consumers and firms benefit from productivity change.

Below we summarise the key findings with regard to productivity growth of the chosen papers.

4.1 Summary of literature review

Figure 22 Literature review summary

	Saal & Parker (2001)	Bottasso & Conti (2009)	Maziotis, Molinos-Senante & Sala Garrido (2017)	Saal, Parker, & Weyman-Jones (2007):
Title	Productivity and Price Performance in the Privatised Water and Sewerage Companies of England and Wales	Price-cap regulation and the ratchet effect: a generalized index approach	Assessing the Impact of Quality of Service on the Productivity of the Water Industry: A Malmquist-Luenberger Approach for England and Wales	Determining the Contribution of Technical Change, Efficiency Change, and Scale Change to Productivity Growth in the Privatised English and Welsh Water and Sewerage Industry: 1985-2000
Technique	Tornqvist TFP growth index	Technical Change (OPEX Productivity) estimated with a translog Variable Cost (OPEX) function using standard panel econometrics, estimated with alternative time trend specifications	Malmquist-Luenberger Productivity Indicator (MPLI), using DEA based input distance function	Generalized Malmquist productivity index (MPI) based on SFA estimated input distance function, and allowing decomposition of TFP growth into efficiency, technical change and scale effects
Sample	10 WaSCs	10 WaSCs	10 WaSCs and 12 WoCs	10 WaSCs
Time period	1985-1999	1995-2004	2001-2008	1985-2000
Measurement of Inputs	Inputs are divided into capital, labour and other costs.	Inputs are divided into capital, labour and other costs. Capital is treated as a quasii-fixed input.	Inputs are divided into capital and operating expenditures	Inputs are divided into capital, labour and other costs.
Measurement of outputs	Water and sewerage outputs are respectively measured by the population served and the population connected to sewerage treatment works.	Water and sewerage outputs are measured by the water delivered and equivalent sewerage population.	This study includes i) the volume of water distributed; and ii) the number of connected properties.	The study respectively includes water delivered and equivalent sewage treatment load as volumetric output proxies for water and sewage.

	Saal & Parker (2001)	Bottasso & Conti (2009)	Maziotis, Molinos-Senante & Sala Garrido (2017)	Saal, Parker, & Weyman-Jones (2007):
Measurement of quality of service	Quality adjustments were made by adjusting the water and sewerage output indices by the relevant quality of service indices. The water quality index is defined as the ratio of the average percentage of each WASC's water supply zones that are compliant with key water quality parameters, relative to the average compliance percentage in 1990. A weighted average of river quality and bathing water quality for each WASC was used to measure sewerage treatment quality improvements.	The studies reported approach estimates the cost effects of a drinking water and sewage quality index, but estimates models with quality adjusted outputs with quality of water measured with a zonal compliance measure, and sewage quality measured apparently based on sewage work compliance. (This is likely to be numerical consent compliance but the text is not clear). It also discusses alternative approaches where these quality indices are directly entered in the cost function, and in which water pressure and supply interruption data were employed similarly.	The three 'undesirable outputs' included in this study are the following: i) total number of written complaints; ii) total number of more than 12 h and 24 h of unplanned interruptions; and iii) Properties below the reference level at the end of year.	The paper further employs the quality adjusted water and sewage population data employed in Saal & Parker (2001) as further outputs designed to capture the impact of the absolute value of quality produced

5 ALTERNATIVE APPROACHES AND NEXT STEPS

5.1 Overview

The analysis presented in this report is based on the Tornqvist TFP growth approach, a commonly employed index number approach, which has been widely used to inform policy and regulatory decisions in the water and other utility sectors in the UK and Europe. A number of regulators in the UK and Ireland (including Ofgem, Ofwat and the CAA) have used TFP growth analysis as their primary evidence for setting productivity targets. A major advantage of index number based TFP growth analysis over other techniques is that it can be implemented when there is a small sample of data.

While a Tornqvist based index number approach, has considerable advantages it also is a standard growth accounting approach, which makes strong assumptions, to allow the use of revenue and cost shares to construct aggregate output and input indices. These include the assumptions:

- of constant returns to scale;
- that inputs are paid the value of their marginal products; and
- that output prices perfectly reflect the values placed on outputs by consumers.

Moreover, by relying on revenue and cost share data, the technique both assumes away the need for and also precludes the ability to directly model how differences in operating environments, structural changes, and differences in quality influence productivity growth. This for example, explains the need for the use of the multiplicative quality indicators in our Tornqvist index approach, as there are significant differences in quality over time in the English water industry.

Our own work in this report has indicated the difficulties in constructing an appropriate quality index with which to adjust the standard Tornqvist index. In section 5.2 we outline potential improvements to the index based approach.

In addition to refining the Tornqvist approach further, we note that recent academic efforts have increasingly focussed on exploring other estimation techniques, such as productivity growth estimates derived from cost and distance functions that can be estimated with econometric techniques, such as standard panel data models and Stochastic Frontier Analysis (SFA) and non-parametric techniques such as Data Envelopment Analysis (DEA). These approaches have a number of advantages, relative to index number based TFP growth analysis. These include the following.

- They are not constrained by the restrictive assumptions on which the Tornqvist approach rests, such as the assumption of constant returns to scale. These alternative approaches can allow for variable returns to scale across firms, for example.

- Importantly, they allow for the direct inclusion of quality and other operating environment variables into the models as explanatory variables for productivity growth, rather than necessitating the use of multiplicative adjustments, as has been done to account for quality indicators in our Tornqvist index approach. In other words, the outputs of water businesses (such as the number of connected properties), quality of service, operating environment, and any other important drivers of productivity growth can be accounted for as separate explanatory variables in econometric and DEA analysis.
- They allow for a more detailed decomposition of the causes underlying productivity growth. This can be useful to address a wider set of questions – relevant to policy and regulation as well as to the industry's own understanding of its performance.

Our literature review suggests a variety of approaches that could provide fruitful avenues for further research. Section 5.2 discuses next steps for improving the index number based TFP growth analysis, as well as potential extensions suggested by the academic literature. Section 5.3, then outlines our recommendations for further research given the strong potential of deriving productivity growth estimates from cost and input distance function approaches, and their estimation with standard panel econometric, DEA, and SFA estimation techniques.

5.2 Next steps – Index based TFP growth analysis

Within the time frame allowed for this project, we have been able to complete the challenging process of collecting and aggregating broadly consistent output and input indices for an aggregate non-quality adjusted TFP growth series for the sector back to 1993. However, we believe there are two particular areas where improvements could be made on our reported models.

Accounting and Cost Definitions

The first relates to the important shift in regulatory accounting in the 2015-16 accounting year, as Ofwat moved from the current cost regulatory accounting definition of costs it had employed for the first 25 years after privatisation, to the new accounting rules that were established when it implemented its new Totex based approach to cost assessment after PR 2014.

In this report, we have broadly chosen to continue employing Professor Saal's approach to total cost measurement based on the old regulatory accounts, and to adjust the 2016 and 2017 data to be backwards compatible. For example this necessitated changes and adjustments to be made to CAPEX, OPEX, and depreciation for those years. We believe that much more detailed work in tandem with accounting experts would improve the consistency of the pre and post 2015 data, and is necessary if future extensions of this approach are to be made.

Similarly, developing an alternative methodological approach that yields a theoretically consistent TFP growth index, based around Ofwat's new regulatory accounting standard based data and restating past data accordingly may improve consistency and be necessary for further extension of the estimated TFP growth series. Related to this, we also believe that further work could be done to develop the realised cost of capital estimates, under both the new and old regulatory accounting definitions.

Adjusting for quality

The second issue relates to the adjustments for quality, and stems from the application of the Tornqvist index approach in a regulated non-competitive sector, where the key basic output variables only effectively move at or near the rate of population growth.

We have in this study augmented the Tornqvist index with quality indicators that aim broadly to be indicators of the value that can be attributed to improvements in drinking and environmental quality. Ideally these values should be based on a consumer valuation of the increased quality, and/or be reflective of the increase in input requirements that are legitimately associated with quality improvements. However, within the scope and timescale of this study, the quality adjustments that we have employed are based on indicators that measure physical improvements in quality. Moreover, a realistic assessment indicates that creating a consistent and comprehensive quality indicator database for the 1991 - 2017 period is in itself a task that requires considerable effort and resource.

We therefore suggest that the work in this study could be developed via the careful collection of a quality indicator database, with industry and regulatory input provided with regard to what indicators should be collected. The collection of the data should also be informed by the design of an appropriate weighting system for these indicators, where weights would be reflective of appropriate costs associated with a given incremental change in the respective quality indicator. We strongly believe that this approach is not only feasible, but would substantially improve the robustness of the quality adjusted TFP series.

Alongside this, we recommend the development of an alternative approach to representing quality via an index derived from a time-series of enhancement capex and opex expenditure. This would present some methodological challenges in its development, but also has strong prospects for providing a credible quality index capturing what costs are legitimately associated with quality change.

Beyond these two suggestions for improving the quality adjustment of the Tornqvist index approach we have implemented, we note that Annex B, Section B.1 further discusses the two following potential extensions of the Saal & Parker (2001) methodology:

- to further follow Saal & Parker (2001) and extend the current analysis to include profit decomposition techniques to illustrate how both consumers and firms have fared as productivity has increased in the industry since privatisation; and
- exploring the use of Fisher indices, and the potential application of index number techniques to cross sectional TFP analysis and regulatory benchmarking as per Maziotis et al (2016).

5.3 Next steps – Other approaches

Econometric and DEA based estimation of cost function and distance function specifications, can provide productivity growth estimates that account for variation in operating characteristics, allow for multiple outputs while also allowing for variable returns to scale across firms, and can also be used to provide appropriate decomposition of productivity growth into efficiency change, technical change, scale change, Moreover, where different sectors have been facing reorganisation, privatisation, regulatory change or consolidation at different times, these approaches can help to separate out these factors from underlying frontier shift.

These approaches also offer a further particularly relevant advantage in this study's context. Provided robust and consistently defined data for relevant quality indicators are available, they allow direct estimation of the cost requirements associated with a given observed quality improvement: As such, in addition to their other advantages, they also provide a widely accepted methodology for controlling for the impact of quality directly in the productivity estimation process. As with Tornqvist adjustments though, the robustness of the work will depend on the robustness of the data, so our recommendations regarding quality improvements data set out above, are also valid with respect to these alternative approaches.

We must note that to date application of these approaches has been extremely limited in the UK regulatory setting, given what we believe are somewhat inaccurate concerns with regard to their relative complexity, extensive data requirements, and requirements for relatively advanced data analysis skills to implement.

We note that their application is more prevalent in other countries, with for example Germany legally requiring the use of both DEA and SFA in electricity distribution, and Scandinavian regulators regularly applying these techniques. These approaches, including both SFA and DEA have also recently been applied by the Australian Energy Regulator, and reviewed in detail by Frontier Economics in Australia. Moreover, examples of their application by academics to the UK regulatory context suggest they can be successfully implemented with the data and skills available in the English regulatory, academic, and consulting communities.

Two key areas of potential development are outlined below. These are:

- productivity estimates derived from **cost functions**; and
- productivity estimates derived from **distance functions**.

We discuss each in turn below.

Productivity estimates derived from cost functions estimated with standard panel or SFA based Econometrics for the 1991-2017 period.

As discussed in Annex B Section B.2, a significant advantage of productivity estimates derived from cost functions is that they rely on a cost based measure of productivity change, thereby providing a readily understood and accepted concept that can be accepted by both regulators and firms who seek to reduce costs by improving productivity.

These approaches require firm level data on costs, input and output quantities, and input prices, with definitions that are consistent with those we have used in this report. However, unlike our Tornqvist analysis, they do not require data on revenues or output prices. This is because the necessary output and input cost weights for constructing the productivity growth index are not imposed but derived from the estimated cost function. Moreover, as operating characteristics and quality indicators can be directly entered in the estimated cost functions, the cost and hence productivity implications of changes in these factors can be directly estimated rather than assumed as is the case with our adjustment for quality in the Tornqvist approach.

Our experience suggests that these approaches are directly estimable based on data drawn from the regulatory accounts available between 1991 and 2015. Thus, a key issue in applying this approach is the data consistency issue created by regulatory accounting changes introduced with the introduction of the Annual Performance Report from 2016. We believe that provided analysts are able to work with industry experts to reconcile these accounting differences there is strong potential to provide both backward compatible cost based productivity growth estimates, and forward looking ones which are more consistent with the new regulatory accounting guidelines.

We note that we have highlighted two alternative but equally appropriate theoretical cost function based approaches in our literature review. These are:

- **Opex cost modelling** with quasi-fixed capital inputs, which will provide partial Opex productivity estimates after controlling for outputs, variable input prices, capital stock investment, quality, and operating characteristics. Provided physical capital stock estimates are available, this approach has an advantage as it does not require assumptions to be made with regard to the price or economic cost of capital stocks. This approach was noted as a strong alternative to Totex modelling by the academic appendix to CEPA(2011) as it provides a theoretically consistent but readily estimable way to control for capex/opex trade-offs. Moreover, Ofwat has commissioned work using this approach in the past.

- **Total Economic Cost** modelling which assumes a long run perspective where capital stocks are also fully variable and which provide estimates of total factor productivity growth, after controlling for outputs, capital and other input prices, quality, and operating characteristics. With regard to input prices, costs, and quantities, this approach is a logical extension of the Tornqvist indices provided in this report as the data and total cost calculations required are conceptually equivalent. However, the significant advantage of the cost function approach is to better capture the impact of differences in operating characteristics and quality in the modelling.

We note finally that we have deliberately focussed on examples where these theoretical modelling approaches can be estimated with traditional econometric techniques. This is because of apparent regulatory hesitancy with regard to applying SFA and DEA analysis. However, as illustrated in Coelli, et al (2003), estimation of a total cost function model with SFA facilitates calculation of Malmquist TFP growth indices that can be decomposed into technical efficiency, technical change, and scale change effects, and that would be particularly useful in estimating cost based productivity trends in regulated industries[18] We finally emphasise that as demonstrated in Coelli, et al (2003) the resulting productivity indices generated from these models can be decomposed so as to provide important insights with regard to how efficiency, scale, and technical change have influenced firm and industry performance.

Malmquist and Other Productivity Growth estimates derived from Distance Functions estimated with DEA or SFA based Econometrics for the 1991-2017 period.

Examples of Malmquist and other productivity growth estimates derived from distance functions approaches are respectively provided in Annex B Sections B.3 and B.4, for applications estimated with DEA and SFA. A significant practical advantage of these approaches is that they only require consistent data on outputs, inputs, and quality and operating characteristics for estimation. In other words, consistent cost, and input price data is not required. This is the case because distance functions effectively allow for the estimation of multiple output production functions, from which both output and input weights can be estimated to respectively construct the aggregate output and input indices required for productivity growth analysis

However, a distance function specification relies on the theoretical assumption that efficiency is present to allow an empirically estimable specification to be derived. Stated differently, this approach does require the combined application of relatively sophisticated economic production theory and estimation with a methodology such as DEA, COLS, or SFA that allows for the presence of inefficiency during estimation.

As our detailed Annex B illustrates further, academic applications of distance functions demonstrates the potential to estimate the underlying production relationships necessary to measure productivity growth in the English and Welsh water industry. Moreover, we note that the most significant barrier to providing consistent data for the pre and post 2015 period results from changes in regulatory accounting requirements. As Malmquist and other productivity growth estimates derived from distance functions no not require consistent cost and input data, these approaches would provide a real practical advantage in relation to our study. Thus, while improving the consistency of some data series should still be a priority, our work on this project strongly suggests that appropriate data sets can be developed to allow estimation of such models for the 1991-2017 period. We recommend further work in this area.

[18] We note that it is even in principle feasible to estimate cost based productivity measures with OLS based specifications, and cost-based Malmquist indices with Corrected Ordinary Least squares specifications.

ANNEX A The data collection process behind the frontier TFP growth model

This Annex outlines the process behind the data collection for the Frontier TFP growth model. It summarises the variables that feed into the calculations and the source for each.

For many of the variables considered, Frontier had to use multiple sources to construct a time series from 1993 to 2017. In addition, there have been changes in accounting standards and definitions over time. Frontier has combined these sources to create seamless transition throughout the period analysed to the extent possible. However, there are minor consistency issues remaining. We discuss these separately for each variable.

Data sources

List of variables required to estimate model

Figure 23 lists the variables needed to construct the Tornqvist index of TFP growth.

Figure 23 Variables needed for the Tornqvist TFP growth model

Variable	Used for	Input or output	Indices or share
Current cost depreciation	Share of capital cost in total cost	Input	Share
Infrastructure renewals charge	Share of capital cost in total cost	Input	Share
Manpower costs, net of infrastructure	Opex index[19]	Input	Share
Closing RCV	Share of capital cost in total cost	Input	Share
Operating expenditure	Opex input usage index and share of operating cost in total economic cost	Input	Share
Ofwat assumptions at each price review	WACC	Input	Share
MEA investment data ▪ replacement cost disposals; ▪ replacement cost additions; ▪ depreciation disposals; and ▪ depreciation charges.	Capital index	Input	Index
MEA net book amount at 31st March 2010	Capital index	Input	Index
RPI, COPI, MM22, SPPI, ASHE	Deflation	Input	Both
Total turnover, and turnover relevant for water or sewerage only	Share of revenue attributable to sewerage and water outputs.	Output	Share
Water & sewerage connected properties	Output index	Output	Index
Various measures (see interim report)	Quality adjusted output index	Output	Index

Source: Frontier Economics, based on Saal & Parker (2001)

Our main priority when collecting data was ensuring consistency between years. This was particularly the case for variables sourced from the regulatory accounts given changes in accounting guidelines post-2015. These variables were:

- capital depreciation costs;
- turnover;
- operating expense; and

[19] Manpower costs are used to separate labour and other costs from total opex, as these are deflate by two different indices.

- MEA investment data.

In the following sections we present the approach to collecting these variables, and all others used in the model.

Current cost depreciation & infrastructure renewals charge

The main area of concern in this area is the switch from the current cost accounting based approach to regulation employed up to 2015 to the new Totex based approach that are required in the new Annual Performance Reports.

Consistent with the approach by Saal & Parker (2001), up until 2015, we calculate depreciation cost by adding data on infrastructure renewals charge and current cost depreciation.

Post-2015, as these variables are no longer available, we use "capital maintenance charges" available in table 4G of the Annual Performance Reports[20]. The series is defined as:

> *"Capital maintenance charge of a similar magnitude to that previously reported for current cost depreciation for above ground assets and infrastructure renewals charges for below ground assets" (Source: Ofwat – RAG 4.05).*

The source of the data and charts presenting the series' are shown below.

Figure 24 Source for capital depreciation costs

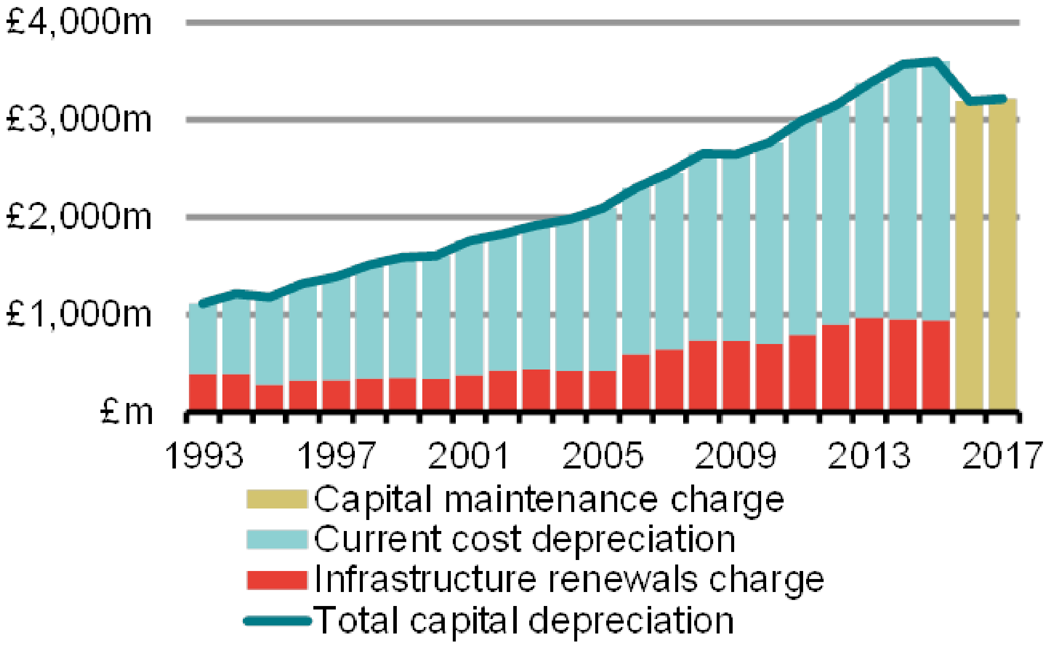
Variable	Source 1993-2007	Source 2008-2011	Source 2012-2013	Source 2014-2015	Source 2016-2017
WaSCs	June returns/regulatory accounts, collected by David Saal			Consolidated regulatory accounts	Consolidated APRs (capital maintenance charge)
WoCs	June returns/ regulatory accounts, collected by David Saal	Consolidated June returns	Consolidated regulatory accounts		Consolidated APRs (capital maintenance charge)

Source: Frontier Economics

Note: Variables sourced separately to 2015.

[20] Table titled "wholesale current cost financial performance"

Figure 25 Capital depreciation cost for all companies, 1993-2017



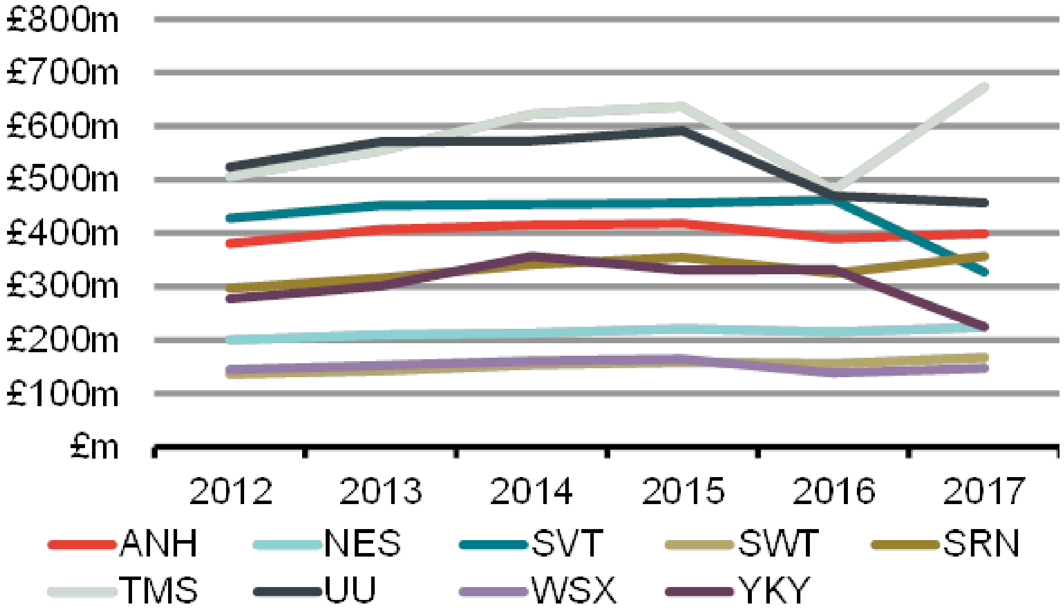
Source: Frontier Economics

Note: Nominal values

Despite using, what we understand to be, a variable consistent with what we have collected in previous years, we still observe a change in the trend of capital depreciation costs post-2015. This is likely driven by decreases for a small number of companies, likely as a result of optional re-evaluations at PR14. Figure 26 shows depreciation costs for each WaSC individually[21].

[21] For the purposes of clarity, WoCs are not included

Figure 26 Capital depreciation costs by WaSC, 2012-2017



Source: Frontier Economics
Note: Nominal values

Turnover

Turnover is used in the output index to calculate the proportion of output that is either water or sewerage related.

Total turnover, and water & sewerage specific turnover exhibits an increasing trend across all-time series. Figure 27 presents the sources of turnover data, and the time series for each variable is presented in Figure 28.

Figure 27 Source for turnover variable

Variable	Source 1993-2007	Source 2008-2011	Source 2012-2013	Source 2014-2017
WaSCs	June returns/regulatory accounts, collected by David Saal		Consolidated regulatory accounts/APRs	
WoCs	June returns/regulatory accounts, collected by David Saal	Consolidated June returns	Consolidated regulatory accounts/APRs	

Source: Frontier Economics

The series illustrates a trend which is consistent with our understanding of events in the sector, e.g. only large year-on-year decrease is after the 1999 price review.

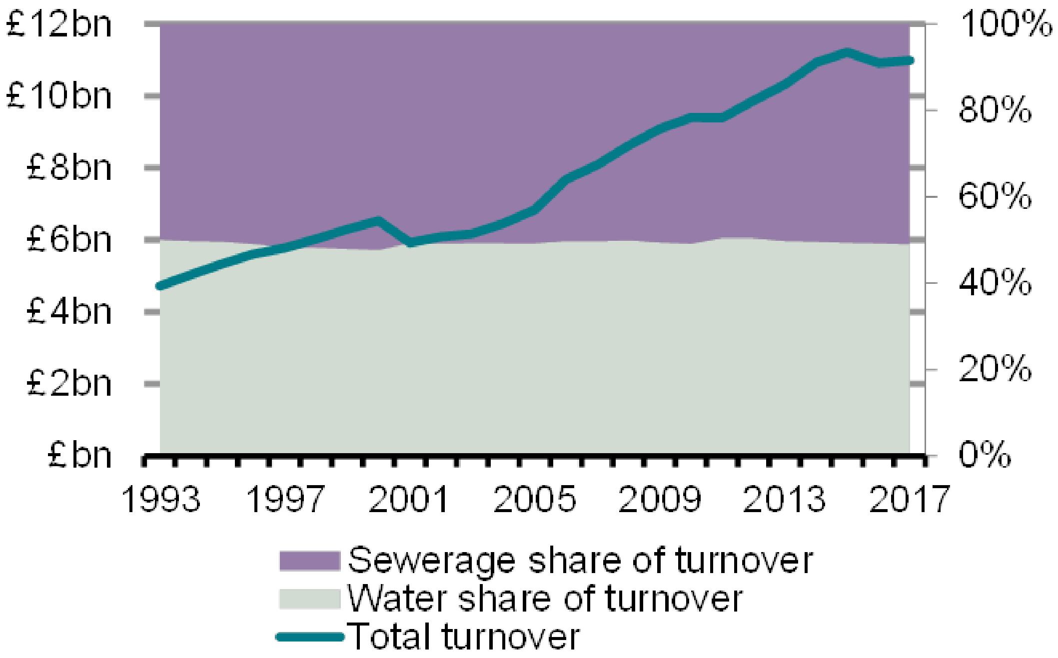
Our understanding is that turnover does not depend on accounting approach, thus, there is no inconsistency introduced as a result of the change in accounting practices post 2015.[22]

[22] Table 4G (of the Annual Reports) provides a useful cross check by presenting the current cost value for wholesale turnover. When this value was compared to the wholesale component of turnover calculated under historic cost practices it was found to be the same.

However, since 2015, retail turnover is reported separately; the model only distinguishes between water and sewerage output. Thus, for WaSCs, our approach to retail turnover has been to allocate it to each of the two types of output on the basis of the split within total non-retail turnover. We note that this is implicitly assuming that share of water/sewerage retail turnover is the same as in total turnover. For WoCs, we recognise that all turnover is water related.

Total turnover and share of turnover that is related to water and sewerage is presented in Figure 28.

Figure 28 Total turnover for all companies, 1993-2017



Source: Frontier Economics

Note: Nominal prices

Operating expenditure

Operating expenditure is another variable where we were concerned about consistency given changes to accounting guidelines post-2015. However, our understanding is that, as operating expenditure does not include depreciation, amortisation, and impairment charges it is not affected by the changes.

To calculate total operating expenditure in 2015/16 & 2016/17 we sum the values for wholesale opex in table 2B and retail opex in table 2C of the Annual Performance Report.[23]

As a result of the change in accounting practices some of what would previously been classed as capex is now classed as opex. This led to an overestimation of opex in these years relative to previous years. Companies still report the amount of opex that they would have capitalised under the previous accountancy practices in the information sharing tables[24] that they submit to Ofwat. Thus, in

[23] Once again, Table 4G gives us a useful cross check to ensure consistency by presenting the current cost value for wholesale opex. When this value was compared to the wholesale component of operating expenditure calculated under historic cost practices it was found to be the same.

[24] Table 1 and Table 8

order to calculate opex consistently in all years we subtract this value from the value reported in the regulatory accounts.

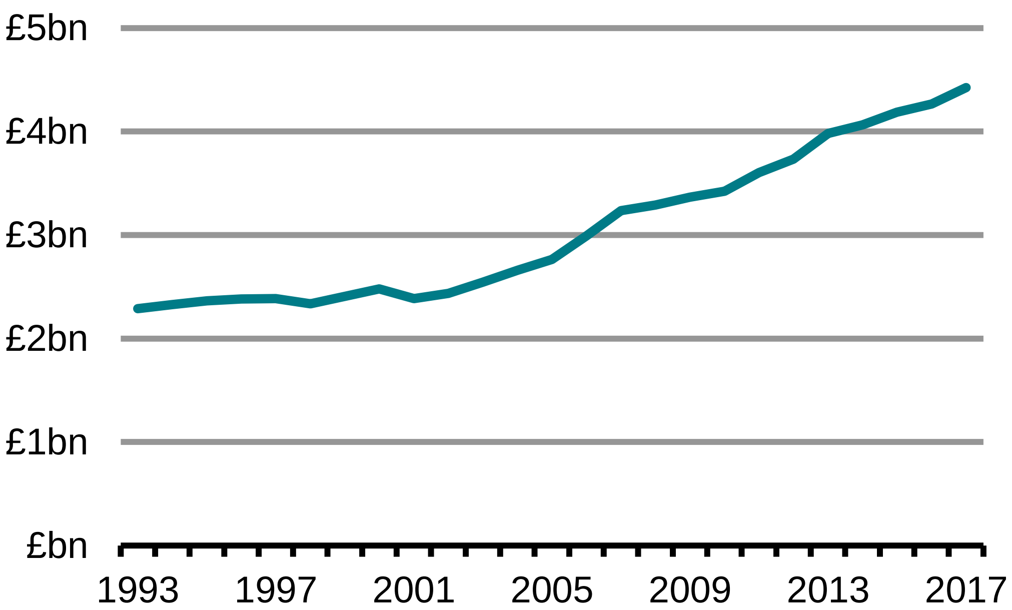
The source of the data and charts presenting the series are shown below.

Figure 29 Source for operating expenditure variable

Variable	Source 1993-2007	Source 2008-2011	Source 2011-2013	Source 2013-2017
WaSCs	June returns/regulatory accounts, collected by David Saal			Consolidated regulatory accounts/APRs
WoCs	June returns/ regulatory accounts, collected by David Saal	Consolidated June returns	Consolidated regulatory accounts/APRs	

Source: Frontier Economics

Figure 30 Operating expenditure for all companies, 1993-2017



Source: Frontier Economics

Note: Nominal prices

MEA values

We collect MEA values for disposal, additions and charges for use in rolling forward the MEA values.

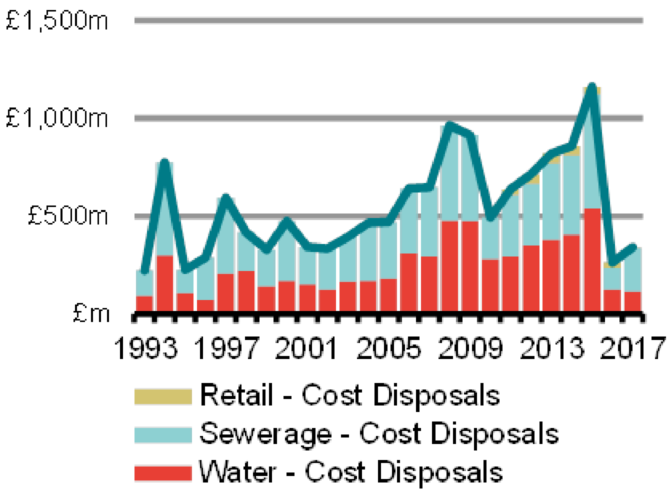
Figure 31 Source for MEA data variables

Variable	Source 1993-2007	Source 2008-2011	Source 2011-2013	Source 2013-2017
WaSCs	June returns/regulatory accounts, collected by David Saal			Consolidated regulatory accounts/APRs
WoCs	June returns/ regulatory accounts, collected by David Saal	Consolidated June returns	Consolidated regulatory accounts/APRs	

Source: Frontier Economics

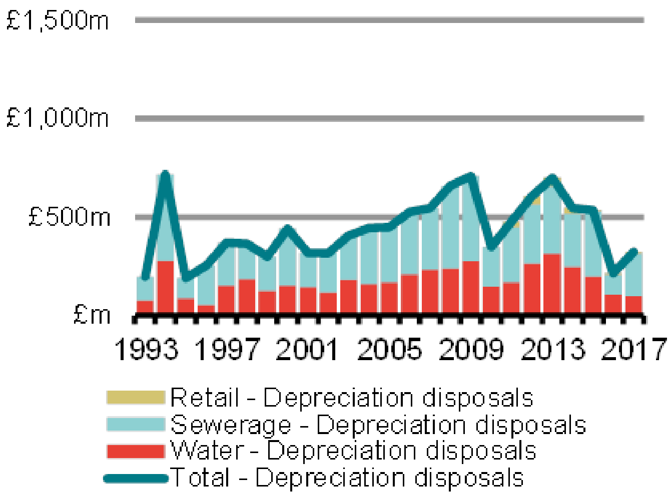
Figure 32 to Figure 35 present the time series for these variables. MEA variables are, by definition, calculated using a current cost accounting policy; therefore, we are not too concerned by inconsistencies post-2015. The degree of variation between years is line with our expectations for the series.

Figure 32. MEA values for cost disposals, all companies, 1993-2017



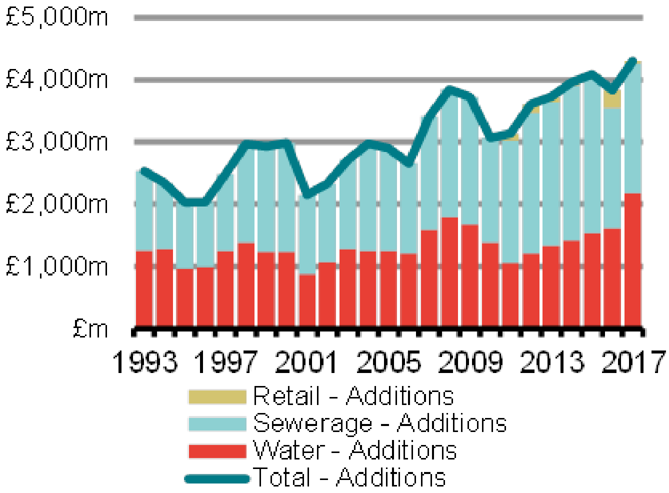
Source: Frontier Economics
Note: Nominal values

Figure 33. MEA values for depreciation disposals, all companies, 1993-2017



Source: Frontier Economics
Note: Nominal values

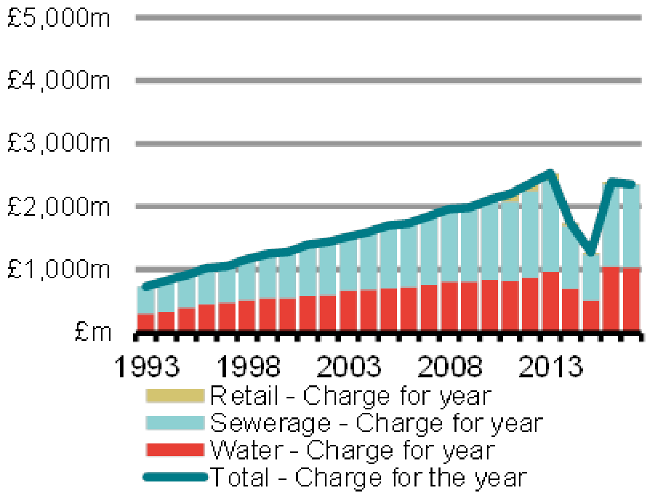
Figure 34. MEA values for cost additions, all companies, 1993-2017



Source: Frontier Economics

Note: Nominal values

Figure 35. MEA values for depreciation charges, all companies, 1993-2017



Source: Frontier Economics

Note: Nominal values

Connected properties

In the aggregate, the time series' for both water and sewerage connected properties exhibits an increasing trend consistent with our expectations.

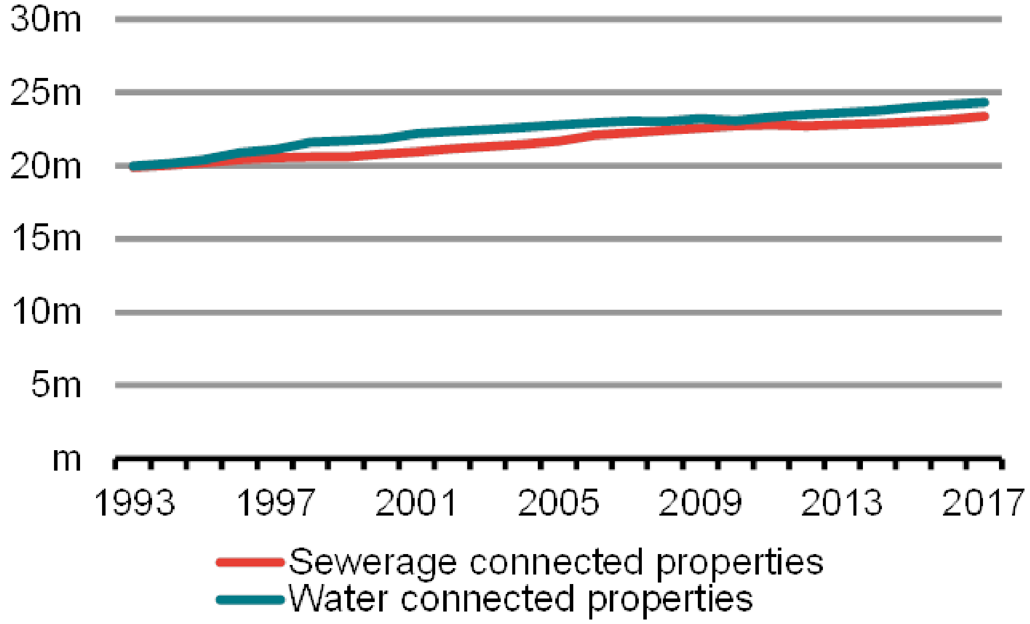
The source of the data and charts presenting the series' are shown below.

Figure 36 Source for connected properties variables

Variable	Source 1993-2007	Source 2008-2011	Source 2011-2013	Source 2013-2017
WaSCs	June returns/regulatory accounts, collected by David Saal			Industry information share
WoCs	June returns/ regulatory accounts, collected by David Saal	Consolidated June returns	Industry information share	

Source: Frontier Economcis

Figure 37 Connected properties for all companies, 1993-2017



Source: Frontier Economics

Regulatory capital values

In the aggregate the industry time series for RCV exhibits an increasing trend.

Data provided to us by Professor Saal was collected in 2010 prices for WaSCs and 2006 prices for WoCs (which we convert to 2010 prices). Data collected from the June Returns and from Ofwat was converted from nominal to 2010 prices using year end RPI. At all times we ensure we were using closing RCV in our data collection.

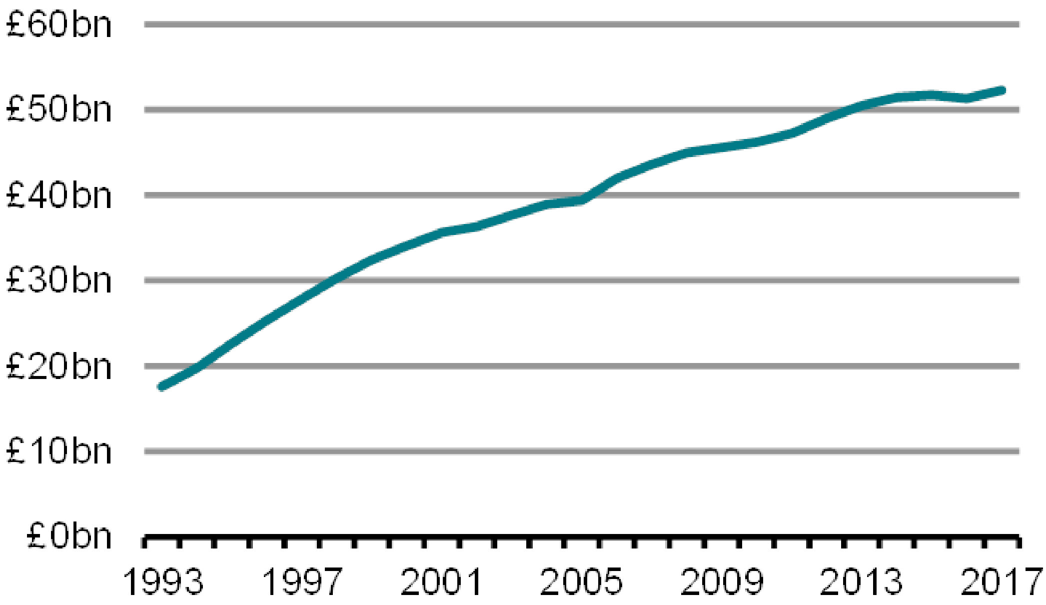
The source of the data and charts presenting the series' are shown below.

Figure 38 Source for connected properties variables

Variable	Source 1993-2007	Source 2008-2011	Source 2011-2013	Source 2013-2017
WaSCs	June returns/regulatory accounts, collected by Professor Saal			Ofwat
WoCs	June returns/ regulatory accounts, collected by Professor Saal	Consolidated June returns	Ofwat	

Source: Frontier Economics

Figure 39 Industry RCV, 1993-2017



Source: Frontier Economics
Note: In 2010 prices

Manpower costs

There was difficulty sourcing manpower costs for all companies in all years. Thus, we were only able to source this data for WaSCs up to 2013. This is illustrated in Figure 40. As Professor Saal has always sourced this data from the limited company returns of the appointed businesses it was not included in the consolidated regulatory account, nor was it included in the industry information share. We were also informed by Professor Saal that some many of WoCs have not historically published the necessary information for labour costs that are also capitalised.

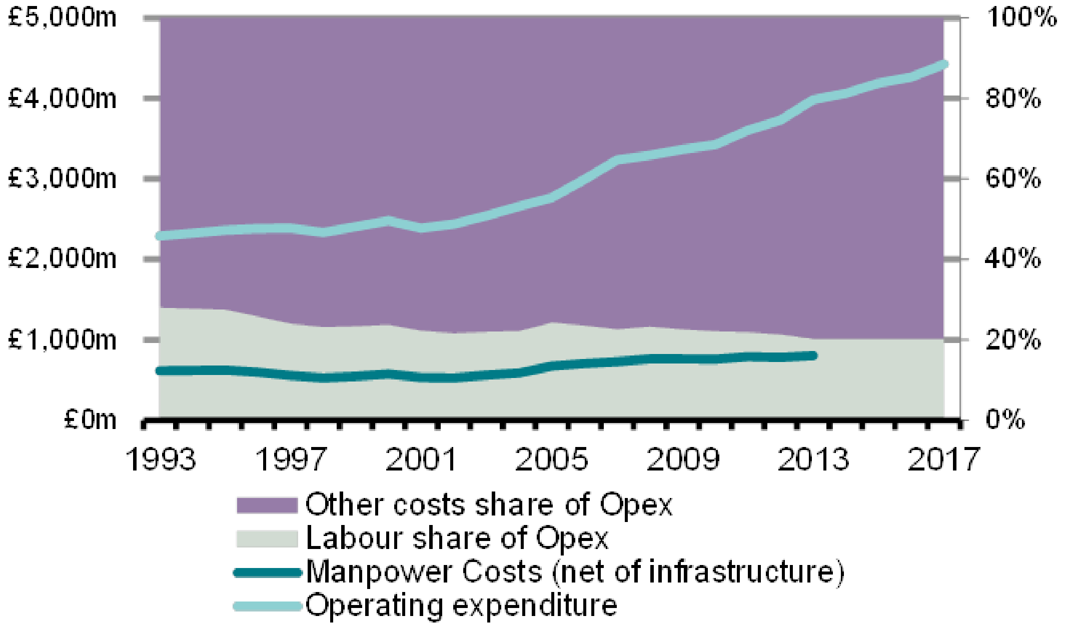
As a result, when constructing the composite opex deflator for the total industry, we used aggregate data for WaSCs as representative of the total industry opex attributable to labour up until 2013. After 2013 we use 2013's estimate for all future years. This is implicitly assuming that the share of labour in opex is the same for WoCs and WaSCs, and, that it does not change beyond 2013.

Figure 40 Source for manpower costs

Variable	Source 1993-2007	Source 2008-2011	Source 2011-2013	Source 2013-2017
WaSCs	Data provided by Professor Saal (financial statements)			N/A
WoCs	N/A	N/A	N/A	N/A

Source: Frontier Economics

Figure 41 Manpower costs (net of infrastructure), operating expense, and cost shares, 1993-2017



Source: Frontier Economics

Note: Opex and manpower costs in nominal values. Manpower costs for WaSCs only

WACC

The WACC is calculated based on assumptions used by Ofwat at each price review. The relevant assumptions used to compute WACC are shown in Figure 42.

Figure 42 Ofwat price review assumptions used to compute real WACC

	1991	1994	1999	2004	2009	2014
Cost of equity (post tax)	6.5%	6.0%	5.5%	7.3%	7.1%	5.7%
Cost of debt (post tax)	4.0%	4.5%	3.2%	3.9%	3.6%	2.5%
Gearing	25%	50%	50%	55%	57.5%	62.5%
Frontier real WACC	5.88%	5.25%	4.33%	5.38%	5.09%	3.67%

Source: Ofwat, Frontier Economics

Price indices

A number of deflators are used in constructing the capital and opex indices. These are included in the 'deflators' sheet within the TFP growth model. They are presented in Figure 43 and

Figure 44, and discussed in more detail below.

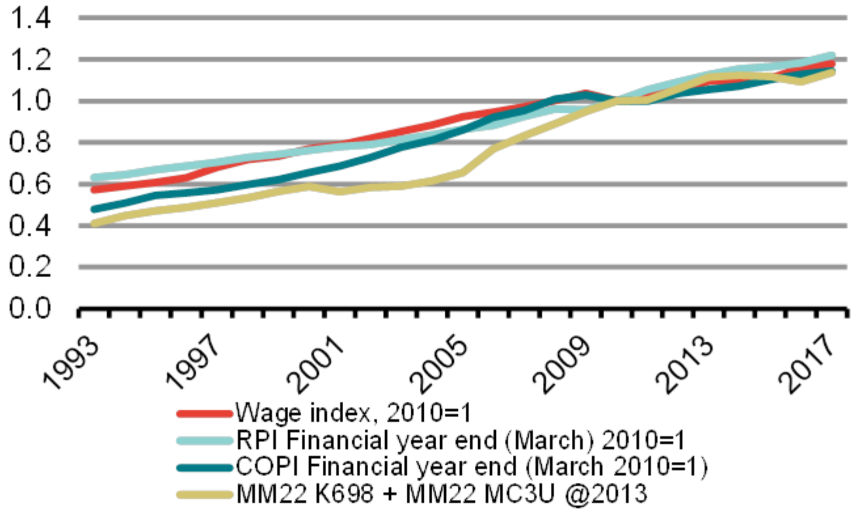
Figure 43 Deflators used in TFP growth model

Deflator	Use	Source
RPI	Adjusting RCV into nominal prices	ONS
Median weekly earnings	Deflating labour component of total opex	ASHE, ONS
MM22 K698 & MM22 MC3U	Deflating the other costs component of total opex	ONS (MM22 K698 only available up to 2013)
COPI – All construction	Deflating MEA net book amount	ONS

Source: Frontier Economics

Note: Financial year end values are used in all cases.

Figure 44 Deflators used in TFP growth model



Source: Frontier Economics

Note: All series indexed to 2010

RPI

We collected closing RCV values in either nominal, 2010 or 2006 prices. To ensure consistency we convert all values to 2010 prices using financial year end RPI. However, given our approach to WACC , we later convert real RCV values into nominal ones. Again, we use financial year end RPI to do this.

Median wages

Saal & Parker (2001) deflate total labour costs using wage costs calculated within the model. However, as we do not have all required observations of this data, we need to use a different source to deflate the labour portion of the opex index.

The sources available are outlined below.

Figure 45 Potential wage deflators

Years	Relevant time series available
1990-1996	▪ Median weekly wages in the whole economy
1997-2009	▪ Median weekly wages in the whole economy; ▪ Median weekly wage in the water supply; sewerage, waste management and remediation activities sector; and ▪ Median weekly wages in the electricity, gas, steam and air conditioning supply sector.
2008-2016	▪ Median weekly wages in the whole economy; and ▪ Median weekly wage in the electricity, gas and water supply sector

Source: Annual Survey of Hours and Earnings, ONS

The series which was constructed is an estimate of median weekly wage in the water supply; sewerage, waste management and remediation activities sector for all years. The table below outlines our approach to estimating this series for years where this data was not available.

Figure 46 Approach to constructing wage series

Years	
1990-1996	We use the 08-16 data to calculate the premium paid to water related services relative to the whole economy. We then multiply the 90-96 whole economy values by this premium.
1997-2007	In 2008 and 2009 we have data on both median weekly wage in the water supply; sewerage, waste management and remediation activities sector from the 08-16 source; and, data on median weekly wage in the electricity, gas and water supply sector from the 97-09 source. Using these two years we are able to calculate the premium (in this case negative) paid to the water sector relative to the wider electricity, gas and water sector. We multiply the 97-08 values for median weekly wage in the electricity, gas and water supply sector by this premium.
2008-2016	We use the values for median weekly wage in the water supply; sewerage, waste management and remediation activities sector.
2017	The data for this year has not yet been produced. To forecast this, we calculate the CAGR in our time series for the 5 years previous and use that to inflate the 2016 value.

Source: Frontier Economics

MM22

MM22 K698, Producer Price Index for Water Supply, is used in Saal & Parker (2001) to deflate other operating costs. Unfortunately, the ONS stopped producing MM22 for the water supply sector in Q2 2013. Therefore, in order to construct a deflator for other costs, from this point we use a different MM22 series, MC3U, Inputs for Water Collection, Treatment or Supply.

Deflated labour costs and deflated other operating costs are summed to calculate total deflated operating costs.

COPI

COPI is used to deflate total MEA net book amount. Our understanding is that responsibility for producing COPI passed from BEIS to the ONS in 2014. Since then the ONS have been producing an interim solution while a new methodology is developed.

In our modelling, up until 2013, we use COPI previously collected by, and shared with us by, Professor Saal. Following this, we use the only source available to us, the interim solution for COPI calculated by the ONS.

ANNEX B LITERATURE REVIEW

In this appendix, we summarise the approach to productivity analysis adopted in the following representative papers drawn from the academic literature.

- Saal and Parker (2001): Productivity and Price Performance in the Privatised Water and Sewerage Companies of England and Wales
- Botasso & Conti (2009): Price-cap regulation and the ratchet effect: a generalized index approach
- Maziotis, Molinos-Senante & Sala Garrido (2017): Assessing the Impact of Quality of Service on the Productivity of the Water Industry: A Malmquist-Luenberger Approach for England and Wales
- Saal, Parker, & Weyman-Jones (2007): Determining the Contribution of Technical Change, Efficiency Change, and Scale Change to Productivity Growth in the Privatised English and Welsh Water and Sewerage Industry: 1985-2000

For each of these studies, we summarise:

- the technique used and sample period covered;
- the measurement of inputs and outputs;
- measurement of and adjustment for quality of service; and
- key results.

Our literature review is not meant to be exhaustive, but is instead illustrative of those approaches that have the greatest potential for providing a more comprehensive analysis of productivity trends in the English water industry. We have therefore focused on highlighting previous academic application in the UK of several methodologies that are most likely to provide productivity estimates that are robust to differences in quality and operational characteristics, and that will deepen the industry's understanding of what factors have contributed to past productivity and may do so in the future. Albeit dated, the Coelli, et al (2003) primer on efficiency and productivity measurement published by the World Bank Institute is illustrative of the variety of methods that can be employed to measure and decompose productivity growth in infrastructure industries.

Section 5 of our report provides more detail of our suggestions for future research. However, we therefore briefly emphasize that we intend the chosen papers to demonstrate: firstly, the potential to extend TFP analysis with the profit decomposition approaches also included in Saal & Parker (2001) which allow an analysis of how both consumers and firms benefit from productivity change; and secondly, the strong potential of deriving productivity estimates from cost and input distance function approaches, which can be estimated with standard panel econometric, DEA, and SFA estimation techniques.

Figure 9 Literature review summary

	Saal and Parker (2001)	Bottasso & Conti (2009)	Maziotis, Molinos-Senante & Sala Garrido (2016)	Saal, Parker, & Weyman-Jones (2007):
Title	Productivity and Price Performance in the Privatised Water and Sewerage Companies of England and Wales	Price-cap regulation and the ratchet effect: a generalized index approach	Assessing the Impact of Quality of Service on the Productivity of the Water Industry: A Malmquist-Luenberger Approach for England and Wales	Determining the Contribution of Technical Change, Efficiency Change, and Scale Change to Productivity Growth in the Privatised English and Welsh Water and Sewerage Industry: 1985-2000
Technique	Tornqvist- Growth Accounting Based TFP index	Technical Change (OPEX Based Partial Productivity Measure) estimated with a translog Variable Cost (OPEX) function using standard panel econometrics, and estimated with alternative assumptions with regard to how technical change is specified in the model	Malmquist-Luenberger Productivity Indicator (MPLI), using DEA based input distance function	Generalized Malmquist productivity index (MPI) based on SFA estimated input distance function, and allowing decomposition of TFP growth into efficiency, technical change and scale effects
Sample	10 WASCs	10 WASCs	10 WaSCs and 12 WoCs	10 WaSCs
Time period	1985-1999	1995-2004	2001-2008	1985-2000
Measurement of Inputs	Inputs are divided into capital, labour and other costs.	Inputs are divided into capital, labour and other costs. Capital is treated as a quasii-fixed input.	Inputs are divided into capital and operating expenditures	Inputs are divided into capital, labour and other costs.
Measurement of outputs	Water and sewerage outputs are respectively measured by the population served and the population connected to sewerage treatment works .	Water and sewerage outputs are measured by the water delivered and equivalent sewerage population.	This study includes i) the volume of water distributed; and ii) the number of connected properties.	The study respectively includes water delivered and equivalent sewage treatment load as volumetric output proxies for water and sewage.

	Saal and Parker (2001)	Bottasso & Conti (2009)	Maziotis, Molinos-Senante & Sala Garrido (2016)	Saal, Parker, & Weyman-Jones (2007):
Measurement of quality of service and	Quality adjustments were made by adjusting the water and sewerage output indices by the relevant quality of service indices. The water quality index is defined as the ratio of the average percentage of each WASC's water supply zones that are compliant with key water quality parameters, , relative to the average compliance percentage in 1990. A weighted average of river quality and bathing water quality for each WASC was used to measure sewerage treatment quality improvements.	The study's reported results are for estimates models with quality adjusted outputs with quality of water measured with a zonal compliance measure, and sewage quality measured apparently based on sewage work compliance. (It also discusses alternative approaches where these quality indices are directly entered in the cost function, and in which water pressure and supply interruption data, as well as network density data are similarly.	The three 'undesirable outputs' included in this study are the following: i) total number of written complaints; ii) total number of more than 12 h and 24 h of unplanned interruptions; and iii) Properties below the reference level at the end of year.	The paper further employs the quality adjusted water and sewage population data employed in Saal and Parker (2001) as further outputs designed to capture the impact of the absolute value of quality produced

Figure 47 Summary of findings across all studies

Study	Time period covered	Findings
Saal and Parker (2001)	1985-2000	The results of this study suggested that while average quality-adjusted TFP growth during 1985-1990 (the transitional/pre-privatization period) was 2.3% per annum, it was only 1.6% during 1990-1999 (the post-privatization era). Also, average quality-adjusted TFP growth was 2.1% during the first period of privatization (1990-1995) but only 1.0% per annum during 1995-1999. It was found that while there has been no statistically significant change in quality-adjusted TFP growth in the post-privatisation period relative to the pre-privatisation period, the overall trend has been downward. Nevertheless, the study suggested that labour productivity had improved over time.
Saal, Parker, and Weyman-Jones (2007)	1985-2000	▪ Total factor productivity, on average, improved by 1.68 percent per year between 1985 and 2000, with almost identical rates of average productivity growth of 1.75 percent 1985-90 (before privatisation) and 1990-95 after privatisation, followed by moderately lower rates of TFP growth of 1.53 percent per annum for 1995-2000. ▪ The decomposition suggests that technical change was stronger in the 10 years after privatisation (2.19 percent per annum) than in the five years before (1.61 percent). However, moderate positive gains from efficiency change before privatisation (0.47 percent per annum) were replaced with even more moderate declines due to efficiency decline after privatisation (-0.16 percent per annum), while steady increases in the scale of the WaSCs contributed a fairly steady negative scale effect to productivity amounting to -0.37 percent per annum between 1985 to 2000. ▪ Overall privatisation improved technical change in the WaSCs, but that efficiency change declined as firms struggled to keep up with a faster moving frontier. Moreover, they confirm the small negative impact of increasing scale in the industry, which is consistent with most credible academic studies which find diseconomies of scale for firms of the average scale of WaSCS.
Botasso & Conti (2009)	1995-2004	This study differs from the other studies in that it provides a partial productivity measure for operating expenditures after treating capital stocks as a quasi-fixed input. As the standard econometrics estimation employed does not allow for efficiency change, the measures of technical change provided are effectively OPEX productivity trends which are also influence by estimated parameters and the resulting impact that input, output and capital stock trends have on productivity growth. The study provides three alternative estimates for annual OPEX productivity growth for 1997-2005 ranging from 1.05 to 1.63 percent per annum. The preferred General index indicates the 1.63 rates and suggests a downward trend, but also a cycle which the authors interpret as a response to the incentives of the 5 year regulatory cycle

Maziotis, Molinos-Senante & Sala Garrido (2016)	2001-2008	▪ The LPI (the quality-unadjusted index) results suggest that water companies´ productivity fell across all years of the study. ▪ The MPLI (the quality-adjusted index) results reported that from 2001 to 2004 water companies made significant efforts to improve the quality of the service provided to customers whereas after 2005 companies' performance regarding customer services was considered as poor. ▪ An analysis at the company level allowed us to identify the primary driver of productivity change. That is the technical change, i.e. the shift of the efficient frontier when quality of service variables are considered. ▪ Accounting for quality of service has a statistically significant impact on the water companies´ productivity change over time.

B.1 Saal and Parker (2001): Productivity and Price Performance in the Privatised Water and Sewerage Companies of England and Wales

Technique and time period

Saal and Parker (2001) measured the TFP and labour productivity of 10 WASCs in England and Wales from 1985 to 1999, using a Tornqvist index, which is one form of a growth accounting based measure of productivity performance . This study compared differences in productivity trends in the transitional/pre-privatisation period (1985-1990) with trends in the post-privatisation era (1990-1999).

Measurement of inputs and outputs

Outputs for this study are measured as follows.

- Water outputs are proxied by the **resident water supply population** served by each WASC
- Sewerage outputs are proxied by the equivalent **sewerage treatment population** for each WASC

Inputs to this study were measured as follows.

- **Non-capitalised labour costs.** As a substantial portion of employment costs in the water industry are attributed to capital projects, an index of non-capitalised employment was generated to avoid the double counting projects. This was done using data on average full-time equivalent employment, and data from the New Earnings Survey on average weekly hours of work in the water industry.
- The basis of the **capital index** is the modern equivalent asset (MEA)[25] estimation of the replacement cost of net tangible fixed assets, as provided in

[25] The adoption of MEA accounting policies by Ofwat creates an additional difficulty as the WASCs make periodic revisions (usually upward) of the current replacement costs of their fixed assets. The reported current cost net fixed asset values were therefore adjusted by backing out the RPI adjusted value of all MEA revaluations made in the 1991-1999 period. This methodology not only removes the arbitrary jumps in capital values that were created by these periodic MEA revaluations, but also generates a capital series that is consistent with the perpetual inventory method.

each WASC's regulatory accounts, for the years 1990 to 1999. The study produced estimates of the replacement cost of the 1985-1989 values that are consistent with the 1990-1999 values[26]. The imputed nominal opportunity cost of capital was calculated as current cost depreciation and infrastructure renewal costs, plus an inflation adjusted rate of return on the replacement cost of the fixed asset base sufficient to provide a 6% post-tax rate of return in real terms.

- **Other input costs** were determined as current cost operating profits less current cost depreciation, infrastructure renewal expenditures, and non-capitalized manpower costs.

Measurement of quality of service

Water and sewerage quality were measured as follows.

- The **water quality index** is defined as the ratio of the average percentage of each WASC's water supply zones that are compliant with key water quality parameters, relative to the average compliance percentage in 1990. The data were drawn from the DWI's annual report on drinking water quality for the years ending 1991-1999[27]. Ofwat's nine water quality measure was chosen as the preferred measure for this study, because these parameters are specifically chosen by the economic regulator as being indicative of parameters that are valued by consumers, and/or have been relatively costly to improve.
- A weighted average of river quality and bathing water quality for each WASC was used to measure **sewerage treatment quality** improvements.

Quality adjustments were made by adjusting the water and sewerage output indices by the relevant quality of service indices.

Summary of key results

The results of this study suggest that while average quality-adjusted TFP growth during 1985-1990 (the transitional/pre-privatization period) was 2.3% per annum, it was only 1.6% during 1990-1999 (the post-privatization era). Also, average quality-adjusted TFP growth was 2.1% during the first period of privatization (1990-1995) but only 1.0% per annum during 1995-1999. It was found that while there has been no statistically significant change in quality-adjusted TFP growth in the post-privatisation period relative to the pre-privatisation period, the overall trend has been downward. Nevertheless, the study suggested that labour productivity had improved over time.

[26] This was accomplished by adding the RPI indexation-adjusted value of the 1990 MEA revaluation to the available current cost net fixed asset data for 1985-1989. As it was considered to be unlikely that any additions to fixed assets which were made between 1985 and 1989 were substantially re-valued in the 1990 MEA revaluation, this methodology should provide a relatively accurate and necessary backward extension of the current cost net fixed asset series

[27] As numerical standards were not applied to drinking water quality before the creation of the DWI, consistent quality data was not available for the period 1985-1990. After consultation with the DWI, it was assumed that drinking water quality in the years 1985-1990 was the same as in the year 1991. This assumption would tend to create a bias favouring greater productivity growth in the post privatization period. However, alternative modelling assuming a backward trend in drinking water quality for the period before 1991, did not significantly alter the conclusions from this study.

Potential Extensions of this Methodological Approach

Saal & Parker(2001) also includes a profit decomposition methodology that constructs a profitability index as the ratio of revenues to economic costs and decomposes this into a TFP effect and a price performance effect. This approach could be employed to illustrate how both consumers and firms have fared as productivity has increased in the industry. A substantial literature using DEA, and econometric approaches also exists and can be employed to pursue profit decomposition after relaxing some the restrictive techniques associated with Tornqvist TFP estimation

Maziotis, Saal, Thanassoulis & Molinos-Senante (2016) provide an extension of Saal and Parrker (2001) by measuring TFP across both time and firms.[28]. The paper also suggests using this methodology in setting X-factors, making further consideration of this paper worthwhile. However, while this approach may be useful to illustrate trends and relative performance differences, caution should be be applied with these hcross sectional index number approaches, which require stronger controls for legitimate difference in input requirements attributable to cross sectional variation in operating characteristics and output quality.

As DEA and econometric approaches can generally better control for such differences in operating characteristic and quality the remainder of our literature review focusses on these techniques.

B.2 Botasso & Conti (2009): Price-cap regulation and the ratchet effect: a generalized index approach

Technique and time period

Botasso & Conti (2009) measures a partial productivity measure which is OPEX productivity growth for 10 WaSCs in England and Wales over the period 19971 to 2005, using a Quasi-Fixed Capital variable cost (OPEX) model. This model has been chosen to illustrate; firstly, the potential for employing cost function models

[28] In the first step, measures of temporal (unit-specific) productivity across time for each firm are provided (Saal and Parker, 2001). Next, productivity comparisons across companies at any given year (multilateral spatial comparisons) are calculated by using a multilateral Fisher index (Balk, 1996; Fox et al., 2003; Pierani, 2009). Then, by reconciling together the spatial and temporal productivity measures into relative productivity measures, a single index is provided that consistently measures productivity performance changes both across firms and over time (Hill, 2002, 2004). Finally, the reconciliation of the spatial, temporal, and relative productivity measures allows us to decompose the unit-specific index number based

It was found that that between 1991 and 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 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, amounting to 19.5% of cumulative productivity growth for the average firm by 2002. The average company continued to achieve a substantial level of catch-up in quality-adjusted productivity until 2005, which are 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 a the relatively loose price review of 2004 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.

to measure productivity growth; secondly, the potential to employ classical econometric techniques to panel data; and thirdly to demonstrate a widely academically accepted and economic theory consistent alternative to the TOTEX approach for controlling for substitution between capital and OPEX. This is accomplished by estimating a model of variable costs which controls for the impact of changes in outputs, capital stocks, and OPEX productivity growth can be obtained as the derivative with respect to time of this function. We further emphasize that while the paper correctly describes its results as estimated technical change, the models and estimation techniques employed imply that this measure is also consistent with productivity growth. e.g. in the absence of assuming technical inefficiency as in DEA and SFA models, estimated technical change is equivalent to a measure of productivity growth.

Measurement of inputs and outputs[29]

Water and sewerage outputs are measured by water delivered and equivalent population, respectively.

Inputs are measures by capital, labour, and "other", as described below.

- **Capital.** Separate water and sewage capital stocks are proxied by Modern Equivalent Asset (MEA) current cost estimates of the replacement cost of the firm's existing capital stock using the approach employed in Saal, Parker, and Weyman-Jones (2007) discussed below[30].
- **Labour.** The average number of full-time equivalent (FTE) employees is sourced from the companies' statutory accounts. Firm-specific labour prices are calculated as the ratio of total labour costs to the average number of full-time equivalent employees.
- **Other costs** in nominal terms are defined as the difference between operating costs and total labour costs. Given the absence of data allowing a more refined break out of other costs, the Bottaso & Conti employ an approach of dividing this nominal cost by the capital stock to create an output proxy. While this approach was once common in some academic papers, it is a relative weakness of this paper as it is better to model these costs with an appropriate input price index for materials and services purchased, as the other studies considered have.

Measurement of quality of service

To test the impact of quality on measured productivity, quality-adjusted measures of output for water and sewerage services are calculated. These are the product of water output and a drinking water quality index, with the former being similar to that employed by Saal and Parker(2001) and the latter based on numerical consent compliance of sewage plants. The authors also discuse but do not present auxiliary models that test the inclusion of these quality variables as independent variables, as well as further models where operating charcacteristcs are also controlled for in the analysis

[29] Using data from Ofwat's published June Returns.

[30] MEA values for previous years based on net investment are also systematically calculated, as is necessary given the periodic substantial revisions of the companies' MEA values.

Summary of key results

The study provides three alternative estimates for annual OPEX productivity growth for 1997-2005: These range from 1.05 to 1.63 percent per annum, with Botasso and Conti's preferred General index providing the higher 1.63 average annual percentage growth rate, but all three approaches suggesting a downward trend. The author's also suggest that the results follow which the authors interpret as a response to the incentives of the 5 year regulatory cycle: e.g. the ratchet effect in the title of the paper.

Potential Extensions of this Methodological Approach

We have explicitly chosen to illustrate a cost function based approach to productivity measurement with the Bottaso & Conti (2009) paper because it provides an academically credible example of an approach where OPEX productivity can be modelled while taking the impact of capital investment on OPEX into account. Moreover, we note that a similar approach was employed in a Stone and Webster report commissioned and published by Ofwat during PR 2004. This report suggested OPEX productivity trends that were consistent with the OPEX X factors that Ofwat was contemplating using in its price review, and also illustrated a methodology which explained the contribution of changes in annual productivity growth that could be attributed to changes in labour, capital, output, and operating characteristics as well as change in the underlying cost relationship over time. We emphasize that the academic appendix to CEPA (2011) strongly supported this approach as a readily estimable and economic theory appropriate approach to allowing for capital opex substitution in the industry. E.g it provides an extremely credible alternative to TOTEX modelling.

An alternative approach (which also allow for long run capital opex substitution effects) is to employ a total economic cost function approach, with definitions of costs, inputs, outputs, and input prices that will be equivalent to those employed in our Tornqvist TFP analysis. Thus, Saal and Parker (2000) provides an illustration of this approach that effectively uses the same underlying data base employed in Saal and Parker (2001). Such total economic cost function approaches have the advantage of yielding estimates of total factor productivity growth, while not only allowing for the estimate impact of controls for exogenous factors and quality, but also relaxing assumptions such as that of constant returns to scale.

We also note that we have also deliberately chosen Bottaso & Conti (2009) as a cost function application that employs traditional econometric techniques, so as to illustrate that econometric productivity modelling can be carried out without employing SFA analysis. However, as illustrated in Coelli, et al (2003), estimation of a total cost function model with SFA facilitates calculation of Malmquist TFP growth indices that can be decomposed into technical efficiency, technical change, and scale change effects, and that would be particularly useful in estimating cost based productivity trends in regulated industries.

We finally note that economics based cost function approaches to productivity growth measurement have two further potential benefits in regulatory application. Firstly, **they estimate cost**, which as a readily understood and accepted concept can be accepted by both regulators and firms, seeking to reduce costs by improving productivity. Secondly, as water and/or sewerage firms tend to produce multiple outputs, they also allow the estimation of productivity in the presence of multiple output production relationships, with standard econometric techniques. This is not the case for the distance function applications illustrated below, which require a theoretical assumption of inefficiency.

In sum, we believe that estimation of both variable cost models controlling for quasi-fixed capital stocks and total cost models, and the respective estimation of partial OPEX productise and total factor productivity measures, would be feasible, and would also provide deeper insights with regard to productivity trends and their determinants in the English water industry.

B.3 Maziotis, Molinos-Senante & Sala Garrido (2017) Assessing the Impact of Quality of Service

Technique and time period

Molinos-Senante, Maziotis & Sala-Garrido (2017) assess the productivity growth of 10 WaSCs and 12 WoCs from 2001 to 2008, focusing only on the water supply service, and excluding the sewerage service from the analysis. Productivity is estimated using a Malmquist-Luenberger Productivity Indicator (MPLI). . The MPLI was used to compute the productivity change of water companies over time by considering the inputs as well as the desirable and undesirable outputs (lack of quality of service). These indicators are derived from a directional distance function using Data Envelopment Analysis (DEA), and the MPLI results are decomposed into two components, namely efficiency change and technical change.

Measurement of inputs and outputs

The two outputs were included in this study.

- **the volume of water distributed**, expressed in megalitres per day (a proxy for the quantity of water abstracted and put into the distribution network); and
- **the number of connected properties** (a proxy for urbanization and size).
- The two inputs involved in the assessment were the capital stock and the operating costs, both expressed in thousands of pounds.
- **the capital stock** was proxied by the cost of a modern equivalent asset, which is based on current cost estimates of the replacement cost of the water companies' existing capital stock. This was following past practice from (e.g. Saal et al., 2007; Maziotis et al., 2015),
- **the operating costs** involved energy costs, labour costs and resource and treatment costs incurred in abstracting and distributing drinking water, as well as business activity costs related to headquarter activities.

Measurement of quality of service

The three ‘undesirable outputs’ included in this study are the following.

- Total number of written complaints, which is a direct measure of the perception by customers of the offered quality of service.
- Total number of more than 12 h and 24 h of unplanned interruptions.
- Properties below the reference level at the end of year. Ofwat requires that water companies supply water constantly and at a pressure which will reach the upper floors of houses. Hence, the number of properties below the reference level at the end of year was considered to be an excellent quality of service variable.
- Additional variables such as drinking water quality or main bursts were also considered to be relevant measures the service quality. However, given the limited number of water companies in the sample, the introduction of more undesirable outputs was not feasible.

Summary of key results

The primary findings of this study can be summarised as follows.

- Firstly, the LPI (the quality-unadjusted index) results suggest that water companies´ productivity fell across all years of the study.
- Secondly, the MPLI (the quality-adjusted index) results reported that from 2001 to 2004 water companies made significant efforts to improve the quality of the service provided to customers whereas after 2005 companies' performance regarding customer services was considered as poor.
- Thirdly, an analysis at the company level allowed us to identify the primary driver of productivity change. That is the technical change, i.e. the shift of the efficient frontier when quality of service variables are considered.
- Finally, accounting for quality of service has a statistically significant impact on the water companies´ productivity change over time.

Potential Extensions of this Methodological Approach

A vast academic literature employs DEA analysis to estimate productivity growth and it determinants, and is beyond the scope of this study to review. However the approaches in this literature have strong potential for application to the English water and sewerage industry.

We have chosen this particular paper as it illustrates both the potential of employing DEA based techniques to productivity analysis and the application of distance functions. Distance functions can be seen as estimating production relationships: But in contrast to production functions, which can only be estimated with a single output, they can be estimated with multiple outputs. As a result, they do not require cost or price data and can be estimated with only data on output and input quantities, and controls for operating characteristics. E.g. they do not require data on costs or input prices. This paper is also particulalry relevant as it explicitly demonstrates how appropriate methodologies can provide direct estimation of the input requirements associated with quality change, and hence productivity change.[31]

While, it does not directly measure productivity growth, we would also like to highlight Pointon and Mathews (2016) which employs Dynamic DEA to estimate efficiency change for the WaSCs during 1997-2011. As this model, allows for quasi-fixed capital stocks and controls for operating characteristics and quality, it provides a very strong illustration of how an appropriate but sophisticated estimation of input requirements relationships can be estimated with DEA. Moreover, it allows us to emphasize that productivity estimation with DEA (or econometrics) is a two stage process, which firstly requires a solid estimation of underlying relationships as demonstrated by Pointon and Mathews (2016), followed by a subsequent step where those relationships are employed to measure productivity and explain its determinants . Moreover, we believe our final chosen paper illustrates this by demonstrating this with an application of an input distance function estimated with SFA analysis, which is then employed to generate a Malmquist TFP index, that can be decomposed into technical change, efficiency change and scale change.

In sum, we believe that analysis of the productivity trends in the English water industry since privatisation, could also be augmented via DEA based modelling, and that there is even scope in the academic literature for such a study.

B.4 Saal, Parker, and Weyman-Jones (2007) Determining the Contribution of Technical Change, Efficiency Change, and Scale Chage to Productivity Growth in the Privatised English and Welsh Water and Sewerage Industry: 1985-2000.

Technique and time period

Saal, Parker, and Weyman-Jones (2007) assess the productivity growth of 10 WaSCs from 19985 to 2000. Productivity is measured using a Generalized Malmquist productivity index (MPI), developed after estimation of an input distance function with panel based SFA econometric techniques. Relative to a standard Malmquist index, the Generalized Malmquist is considered a true TFP index. This is because it not only accounts for efficiency change (EC) and technical change (TC), but also returns to scale (RTS).

This paper extended the analysis of Saal and Parker(2001) by employing a TFP estimation technique that allows for output and input weights that control for variation in input requirements attributable to differences in quality and operating characteristics. Moreover, the number of outputs employed was expanded in an

[31] But also note that this benefit is not limited to DEA modelling, as all f the econometric and DEA based approaches reviewed here can be employed to estimate to what extent operating characteristics influence input requirements and hence productivity.

effort to control for both general outputs and the absolute value of quality produced, e.g so as to directly allow for the impact of quality on the estimated input requirements of companies. In sum this approach allows for cross sectional efficiency estimation, and also provides true TFP growth estimates after controlling for differences in operating characteristics and quality.

Measurement of inputs and outputs

Two volumetric outputs were included in this study to capture base output and scale characteristics.

- **the volume of water distributed**, expressed in megalitres per day, and thereby representing base water volumes delivered to customers net of leakage

- **Equivalent Sewerage load, which was the standard measure in the industry for the physical treatment load of a WasC immediately before and after privatisation**

Two further quality adjusted measures of population servied were employed and justified on the grounds that quality investments most directly impact the proportion of customers able to receive a given drinking water quality or sewerage treatment standard, and increasing the number of customers with better service is the direct goal of quality improvements. These quality measures were based directly on those developed in Saal and Parker (2001).

- **Quality Adjusted Connected Water Population**, expressed in megalitres per day, and thereby representing base water volumes delivered to customers net of leakage.

- **Quality Adjusted Population Connected to Sewage Treatment Works Equivalent Sewerage load, which was the standard measure in the industry for the physical treatment load of a WasC immediately before and after privatisation.**

The underlying inputs used in this paper were identical to those used in Saal and Parker(2001), , However this approach only requires proxies for physical input usage, as input index weights are estimated from the input distance function as opposed to derived based on weights in the assumed total economic cost. Similarly,, revenue data is not required as output index weights are obtained from estimated output elasticities.

- **Capital.** The capital stock is proxied by Modern Equivalent Asset (MEA) current cost estimates of the replacement cost of the firm's existing capital stock.
- **Labour.** The average number of full-time equivalent (FTE) employees, is sourced from the companies' statutory accounts, and adjusted to account for labour used for own-work capitalized.
- **Other Inputs costs** in nominal terms are defined as the difference between operating costs and total labour costs. Given the absence of data allowing a more refined break out of other costs, the UK price index for materials and fuel purchased for the purification and distribution of water, was employed to create a proxy for the real deflated use of other inputs.

Measurement of quality of service

The underlying output adjustment approach is based on the approach detailed above for the Saal and Parker(2001) paper, but the impact of quality on productivity is estimated via he impact on estimated output elasticities and input requirement shares, and can be improved based on current best practice.

Other Operating Characteristics

The methodology employed can be extended to allow for further control variables and the estimated input distance function includes controls for the the type of water source (% underground water) the composition of treatment loads (trade effluent intensity) controls for coastal treatment and or presence of bathing beaches with strict environmental controls (bathing water intensity) and finally controls for whether customers have metered water (% metered water).

Summary of key results

The results from this study indicate that total factor productivity, on average, improved by 1.68 percent per year between 1985 and 2000, with almost identical rates of average productivity growth of 1.75 percent 1985-90 (before privatisation) and 1990-95 after privatisation, followed by moderately lower rates of TFP growth of 1.53 percent per annum for 1995-2000.

Delving into the decomposition of these trends, the results suggest that technical change was stronger in the 10 years after privatisation (2.19 percent per annum) than in the five years before (1.61 percent). However, moderate positive gains from efficiency change before privatisation (0.47 percent per annum) were replaced with even more moderate declines due to efficiency decline after privatisation (-0.16 percent per annum), while steady increasing scale of the WaSCs contributed a fairly steady negative scale effect to productivity amounting to -0.37 percent per annum between 1985 to 2000.

These results therefore suggest that privatisation improved technical change in the WaSCS, but that efficiency change declined as firms struggled to keep up with a faster moving frontier. Moreover, they confirm the small negative impact of increasing scale in the industry, which is consistent with most credible academic studies which find diseconomies of scale for firms of the average scale of WaSCS.

Recent UK Example of SFA Distance Function Estimation

We note that Brea-Solis, Perelman, and Saal (2017) provides a recent example which estimates a similar input distance function approach, for WoCs and WaSCs for 1996 to 2010, but only focusing on water activities. While this paper uses the resulting input distance function estimates solely to calculate shadow prices of water losses it demonstrates the feasibility of estimating an appropriate input distance function, that could also be employed to calculate and decompose a Generalised Malmquist Productivity Index, Moreover, this paper also demonstrates:

- The feasibility of estimating an input distance function while only allowing for a single opex based input and capital stocks (and consistent with the specification employed in our reported Tornquvist productivity growth estimates).

- The feasibility of controlling for volume, connection, and area served proxies in estimating water input requirements. E.g. allowing for a full spectrum of basic network output characteristics.
- Allowing for a negative attribute such as losses and capturing its input requirement, and potentially its.
- The ability to control for a variety of different operating and quality control variables when estimating input requirements.

Potential Extensions of this Methodological Approach

The two SFA based papers we have discussed demonstrate both an application to measure productivity growth in English and Welsh water, and the likely feasibility of estimating and extending this earlier work with current data. As these models allow controls for operating characteristics and quality, and also allow productivity to be decomposed in to efficiency change, technical change, and scale change, we believe it would be particularly appropriate to apply them to the analysis of productivity trends for entire post privatisation period.

ANNEX C LITERATURE ON COMPARATOR SECTORS

Ofgem's approach in DPCR5, RIIO-GD1 and RIIO-T1

In Ofgem's previous electricity distribution price control (DPCR5), gas distribution price control (RIIO-GD1) and electricity transmission price control (RIIO-T1), it measured productivity growth by assessing the average historical improvement in TFP growth for comparator sectors of the economy over a 30-year period. Ofgem's estimates were derived from TFP growth measures reported in the UK data from the EU KLEMS dataset.

Ofgem stated that its comparator sectors were chosen based on the similarity of their business processes to the gas and electricity networks, i.e. their comparable use of labour, materials and other inputs in the production process. Ofgem's comparator sectors included[32]:

- Manufacture Of Chemicals & Chemical Products (24);
- Manufacture Of Electrical & Optical Equipment (30-33);
- Manufacture Of Transport Equipment (34-35);
- Construction (F);
- Sale, Maintenance & Repair Of Motor Vehicles/Motorcycles; Retail Sale of Fuel (50) ;
- Transport & Storage (60-63); and
- Financial Intermediation (J).

We note that Ofgem excluded the electricity, gas & water supply sector because:

- it expects the historical productivity will have captured the impact of privatisation, the introduction of incentive based regulation and structural changes;
- it incorporates the upstream supply and production sectors, which are not comparable to the distribution and transmission sectors.

There are two measures of TFP growth that can be calculated from the EU KLEMS database: a value added (VA) measure and a gross output (GO) measure.

- VA is a measure of the value of gross output minus the value of intermediate inputs (energy, materials and services) required to produce the final output. The inputs for VA are therefore labour and capital.

[32] Ofgem (2012), 'RIIO-T1/GD1: Initial Proposals – Real price effects and ongoing efficiency appendix', July

- GO is a measure of the value of the output of an industry, i.e. the combined turnover of the companies within that industry. The inputs for gross output are therefore capital, labour, energy, materials and services.

In determining its ongoing efficiency assumptions, Ofgem drew on evidence from both GO and VA measures of productivity. Ofgem stated that it has considered the range of productivity measures from the EU KLEMS dataset along with the evidence provided by the network companies and previous regulatory decisions.

ORR's approach for Network Rail

For its 2009-10 to 2014-15 price control period for Network Rail, the ORR relied on "TFP composite benchmarks" for Network Rail which were calculated by Oxera[33]. Separate benchmarks were calculated for four different categories of Network Rail's expenditure: operating expenditure, maintenance, renewals and enhancements. Each benchmark was calculated using a weighted average of the estimates of the historical growth in total factor productivity (TFP) for selected sectors of the UK economy, using data from the EU KLEMS database. The weight for each expenditure category was calculated by its average proportion of total spending over the five year period.

The ORR's choice of comparator sectors was based on a mapping of each of Network Rail's activities to one of more comparator sectors of the UK economy for which data on TFP growth was available from the EU KLEMS dataset. For example:

- Network Rail's 'track maintenance' activity was mapped to two sectors in the EU KLEMS dataset, 'the transport and storage sector' and 'the electricity gas and water supply sector'; and
- Network Rail's 'telecoms' activity was mapped to the 'post and telecommunications sector' in the EU KLEMS dataset.

The following sectors were considered to be comparator sectors, and were 'mapped to' to at least one of Network Rail's activities.

- Electricity, gas and water supply
- Construction
- Transport and storage
- Post and telecommunications
- Financial intermediation
- Renting of machinery and equipment and other business activities.

Oxera's TFP growth rates were derived using the VA measure of productivity. These VA TFP growth numbers were then combined with the weights for each expenditure category to form the "composite benchmarks" used by the ORR.

In January 2011, the ORR commissioned Reckon LLP to carry out an update of Oxera's original analysis. In Reckon's update of Oxera's work, it derived growth

[33] Oxera (2008), 'Network Rail's scope for efficiency gains in CP4', April

rates using both the VA and GO measure of productivity over the period 1970 to 2007. Reckon also questioned the basis of Oxera's mapping of Network Rail's activity to sectors in the EU KLEMS data, and did not use "composite benchmarks" as its preferred measure. Instead, Reckon presented the range of observed productivity estimates using both the VA and GO measure of TFP growth across a number of sectors over the period 1970 to 2007.

Ofwat's approach in PR09

The last significant analysis Ofwat published in this area was at PR09. In PR14 the regulator did not undertake TFP growth analysis, rather incorporating 'frontier' shift by way of estimating a time trend in its econometric analysis. We have requested the underlying study behind Ofwat's PR09. However, it has not been made available to us to consider for this study.

Previous First Economics study for Water UK

In First Economics' June 2008 report for Water UK[34], for the purposes of analysing trends in opex, data for three generic types of sectors were considered to be especially interesting:

- **Production:** sectors in which a product is being processed or produced. Comparator sectors from EU KLEMS in this sector were selected to be 'manufacturing and chemicals', which demonstrated an average productivity improvement for the period of 2.35% p.a.;
- **Network maintenance:** sectors where firms are repairing / maintaining existing assets or networks. Comparator sectors from EU KLEMS in this were selected to be:
  - electricity, gas and water supply;
  - sale, maintenance and repair or motor vehicles; and
  - transport and storage.

  These industries showed an estimated average productivity improvement for the period of 1.35% p.a.
- **Business service provision:** sectors where the core activity is the provision of a business service. Comparator sectors from EU KLEMS in this sector were selected to be finance, insurance, real estate and business services, which demonstrates an average productivity improvement for the period of 0.2% p.a.

First Economics' TFP growth rates were derived using the VA measure of productivity between the 1990 to 2005 period. First Economics subsequently estimated a 'composite benchmark' by weighting the different TFP VA growth rates for comparator sectors in line with the 'nature of work' involved in running a water and sewerage network. First Economics' weighted average annual TFP growth rate was estimated to be 0.83%.

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[34] First Economics (2008), 'The rate of frontier shift affecting water industry costs – a report prepared for Water UK', June

Consolidated list of sectors considered in Frontier's study, drawing on precedent from studies commissioned by Ofgem, Ofwat, ORR and Water UK

Our review of the relevant precedent in the sections above suggests that there is significant overlap in the comparator sectors considered in the relevant studies commissioned by Ofgem, Ofwat, ORR and Water UK. Our consolidated list of sectors to be considered in this study is summarised below.

- Electricity, gas & water supply
- Manufacture Of Chemicals & Chemical Products;
- Manufacture Of Electrical & Optical Equipment;
- Manufacture Of Transport Equipment;
- Construction;
- Sale, Maintenance & Repair Of Motor Vehicles/Motorcycles; Retail Sale of Fuel;
- Renting of machinery and equipment and other business activities.
- Finance, insurance, real estate and business services
- Financial Intermediation.
- Transport & Storage; and
- Post and telecommunications

As we do not consider it possible to achieve an accurate and robust mapping of the costs of water and sewerage businesses with sectors in the EU KLEMS dataset, we do not propose to derive a 'composite benchmark' considered in some of the studies reviewed in sections above.

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