Appendix 8a:
Wholesale and cross-sector efficiency benchmarking and triangulation

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July 2018

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WHOLESALE AND CROSS-SECTOR EFFICIENCY BENCHMARKING AND TRIANGULATION

A report for Yorkshire Water

CONTENTS

1. Executive summary

This report summarises the results of our within-sector and cross-sector benchmarking analysis, which brings together and develops research undertaken by the industry and others. Overall, the within-sector benchmarking evidence suggests that Yorkshire Water is cost efficient in relation to both Network Plus price controls, but may be able to make efficiency savings in relation to the water resources and bioresources price controls. The cross-sector benchmarking evidence suggests that water industry has kept pace with other sectors.

1.1 Introduction and objectives

Yorkshire Water (Yorkshire) asked Economic Insight to develop a body of "top down" benchmarking evidence to help inform and stress-test its business plan assumptions regarding the scope for catch-up efficiency between 2020 and 2025.

In particular, Yorkshire asked us to:

- first, undertake **within-sector benchmarking**, using the econometric models developed by **Ofwat**, **Oxera** and **Economic Insight**; and
- second, undertake **cross-sector benchmarking**, drawing on existing estimates of real unit operating expenditure (RUOE) and our own up-to-date RUOE analysis in relation to the **energy**, **airport** and **rail sectors**.

The evidence set out in this report will form one part of a wide pool of evidence, including "bottom up" evidence, that Yorkshire uses to arrive at its final business plan assumptions. The benefit of using a wide pool of evidence is that it recognises that different sources of evidence have different strengths and weaknesses, and that the true scope for catch-up efficiency may differ from that implied by any one source.

1.2 Summary of within-sector benchmarking findings

Overall, the within-sector benchmarking evidence suggests that:

- Yorkshire is cost efficient in relation to both the Network Plus water and wastewater price controls;

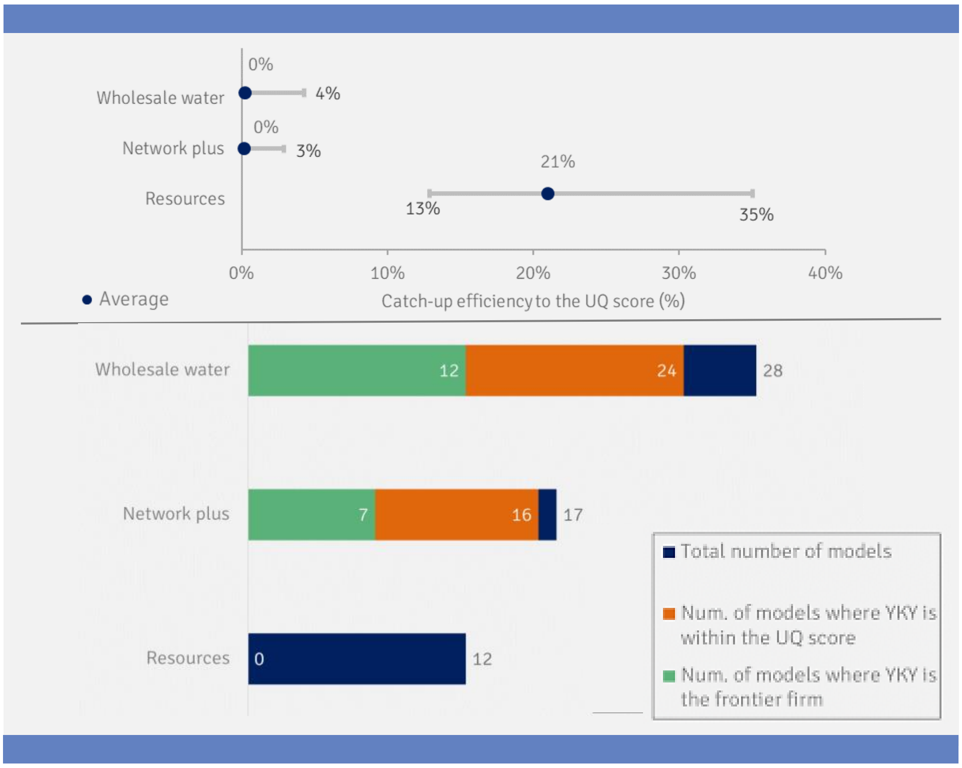
- there may be scope of cost savings in relation to both the water resources and bioresources price controls. However, the existence and magnitude of them is very uncertain, given the limitations of the benchmarking models.

1.2.1 Water services

As illustrated by Figure 1 below, our key findings from the within-sector benchmarking for water services are as follows.

- For **wholesale water**, Yorkshire's efficiency score to the upper quartile (UQ) is between 0% to 4% with an average score of **0%.**[1]
- The efficiency range for **water network plus** is 0% to 3% with an average score of **0%.**
- The range for **water resources** is both higher and wider, between 13% **-** 25% with an average catch-up efficiency to the UQ score of **21%.** However, for the reasons set out in this report, we are less confident in the water resources models and suggest that less weight should be attached to them in favour of other evidence.

Figure 1: Efficiency score ranges in water for Yorkshire



Source: Economic Insight

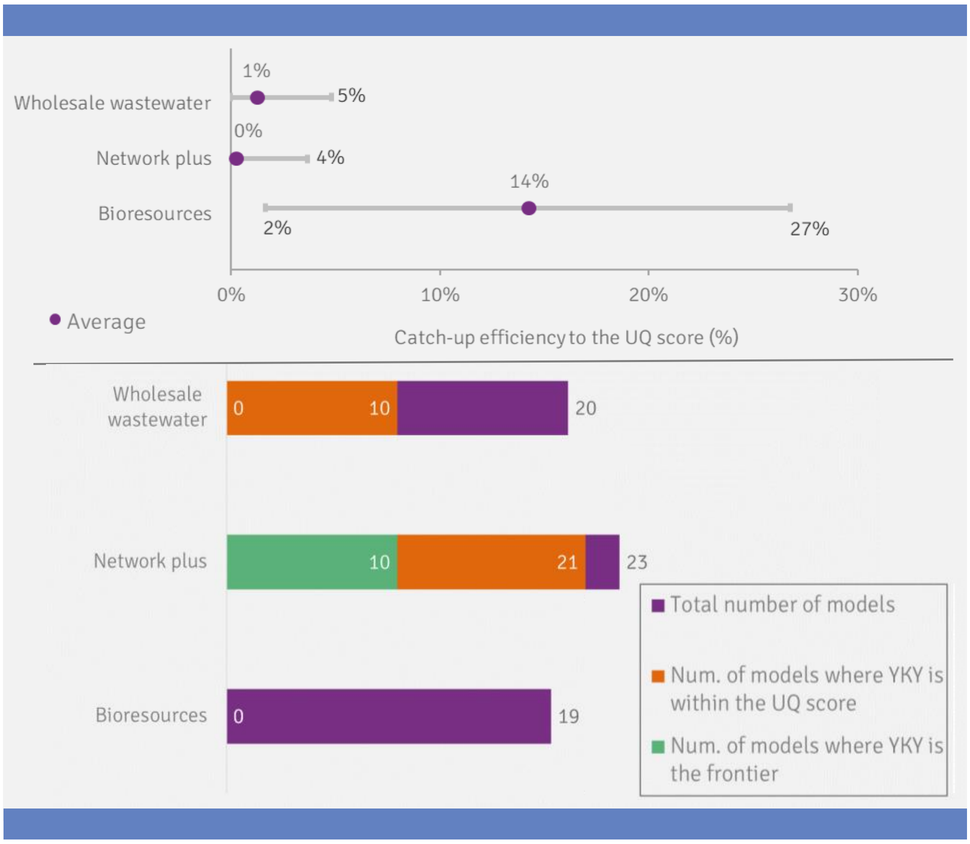
[1] *Note that the average efficiency estimates above are the average of the efficiency scores after they have been rebased to 0%, in the cases where Yorkshire is more efficient than the UQ. The implication is that it does not give Yorkshire the benefit of being ahead of the UQ in some of the models and as such, makes Yorkshire appear more inefficient than it is. We have taken this approach to obtain a range that can be interpreted intuitively.*

1.2.2 Wastewater services

As illustrated by Figure 2 below, our key findings from the within-sector benchmarking for wastewater services are as follows.

- For **wholesale wastewater**, Yorkshire's efficiency range to the UQ score is between 0% to 5% with an average of **1%.**
- The efficiency range for **wastewater network plus** is 0% to 4% with an average score of 0%.
- The efficiency range for **bioresources** is between 2% - 27% with an average of **14%.** Again, we are less confident in the bioresources models and suggest that less weight should be attached to them in favour of other evidence.

Figure 2: Efficiency score ranges in wastewater for Yorkshire



Source: Economic Insight

1.3 Summary of cross-sector benchmarking findings

Overall, the cross-sector benchmarking evidence suggests that the trends in RUOE in the water industry and Yorkshire specifically has "kept pace" with other sectors:

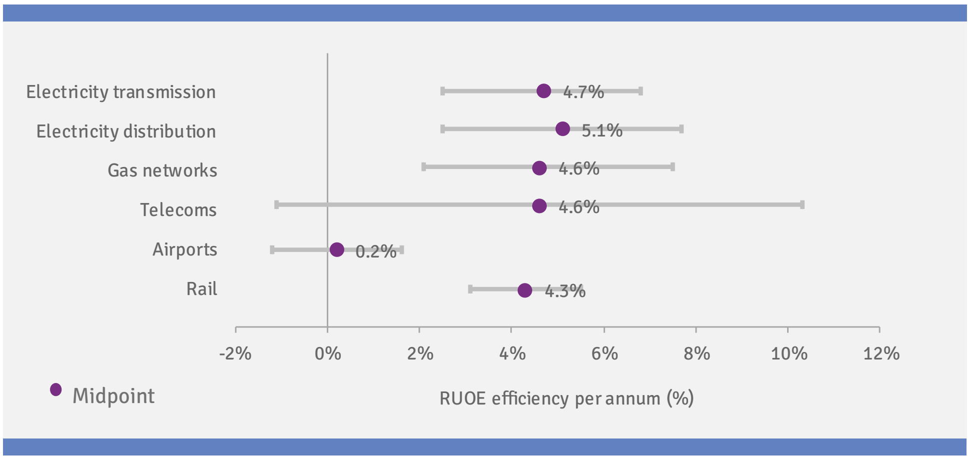
- first, the rate of RUOE reductions has fallen in recent years, from around 4-5% from the 1980s to 2010s to around 1-3%;
- second, the rate of RUOE reductions in the water and waste water sectors is similar to other sectors; and
- third, Yorkshire's rate of RUOE reduction is within the range of other companies from the same sector and other sectors.

1.3.1 Existing literature – RUOE changes between 1980/81 to 2012/13

Our review of the existing literature covered six other sectors between 1980/81 and 2012/13. The results of our review are shown in Figure 3, which shows that:

- first, across the sectors, RUOE fell between 0.2% per year (airports) and 5.1% per year (electricity distribution);
- second, RUOE fell between 4% and 5% per year in five of the six sectors, with airports being the "outlier" at 0.2%; and
- third, there is significant unexplained variation *within* sectors in terms of the size of the RUOE reduction – for example, in electricity distribution the figures range from around -10% to +5%.[2]

Figure 3: Average annual reductions in RUOE per annum from our literature review (1980/81 – 2012/13)



Source: Economic Insight

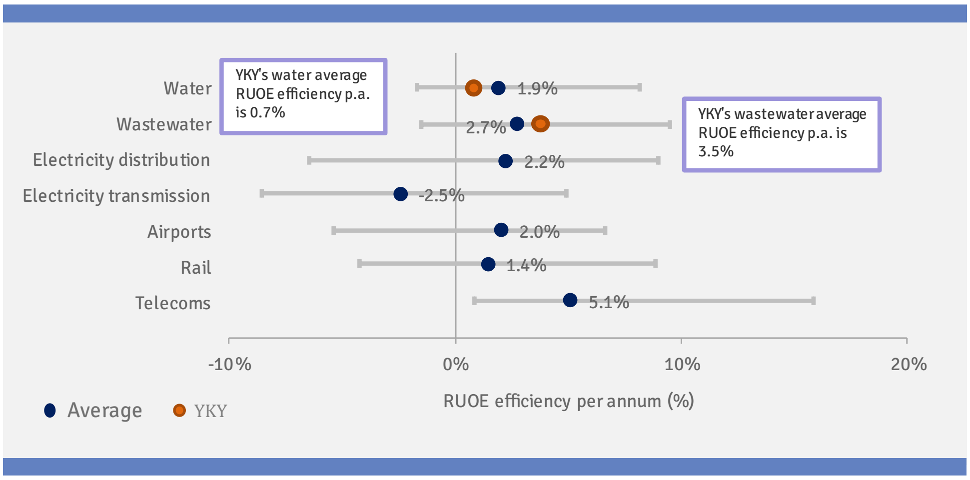
[2] The minimum (maximum) point for each sector corresponds to the lowest (highest) estimate in the literature for each sector. The midpoint is the halfway point between the minimum and maximum points.

1.3.2 New analysis – RUOE changes between 2011/12 and 2016/17

To update the RUOE analysis, we collected data from seven sectors (including water and wastewater) covering the period 2011/12 to 2016/17. The results of our analysis are shown in Figure 4.[3] The figure shows the following results.

- RUOE fell by between 1% to 3% in most sectors from 2011/12 to 2016/17 - and therefore the rate of RUOE reductions appears to have fallen compared to the earlier period covered by the existing literature.
- RUOE in the water and wastewater sectors has fallen at a similar rate to other sectors (1.9% and 2.7% respectively) – with the exceptions of electricity transmission (where RUOE has increased) and telecoms (where RUOE has decreased faster at 5.1%).
- Regarding Yorkshire's RUOE, the figures show that:
  - for wastewater, its RUOE reduction (3.5%) is comfortably within the range associated with other wastewater companies and companies in other sectors; and
  - for water, its RUOE reduction (0.7%) is lower, but still within the range of other water companies and companies in other sectors. One explanation for this is that Yorkshire is relatively efficient and so its opportunity for achieving RUOE is lower than it is for other less efficient companies.

Figure 4: Average annual reductions in RUOE per annum from our data analysis (2011/12 - 2016/17)



Source: Economic Insight

[3] *The minimum (maximum) point for each sector corresponds to the year in which the average RUOE across firms in the sector was the lowest (highest). The average figure is the average RUOE across all firms and years included in our sample.*

1.4 Conclusions and recommendations

On the basis of the within-sector benchmarking evidence, our main conclusions are that:

- in relation to both Network Plus controls, any efficiency savings are likely to be challenging and ambitious, though not necessarily unachievable;
- in relation to the resources and bioresources controls, there appears to be scope for making efficiency savings, though the existence and precise magnitude of them is very uncertain due to limitations of the top-down benchmarking models.

In view of the above we recommend that, particularly in relation to the resources and bioresources controls, Yorkshire supplements and stress-tests the efficiency savings implied by the benchmarking models with other information – including bottom-up evidence – before finalising its business plan assumptions.

Finally, we consider that these conclusions and recommendations are robust to the cross-sector benchmarking evidence for two reasons:

- first, the evidence suggests that the water sector and Yorkshire specifically has kept pace with other sectors; and
- second, it is hard to interpret a high or low RUOE number as either representing a high or low opportunity for making future efficiency savings. This is because RUOE is likely to measure the combination of several factors, including changes in: catch-up efficiency; dynamic efficiency; quality; quantity; and, potentially, measurement error and changes over time.

1.5 Structure of the report

The remainder of this report is structured as follows:

- Chapter 3: sets out our methodology for our within- and cross-sector analysis.
- Chapter 4: presents our results for water services.
- Chapter 5: presents our results for wastewater services.
- Chapter 6: sets our results from the cross-sector benchmarking analysis.

2. Methodology

2.1 The consensus approach to deriving efficiency scores

In this section we provide an overview of our "**consensus approach**". Our aim here is to bring together learnings from across the industry. As such, we bring together three suites of models in our analysis:

i) **Ofwat**'s suite – this includes all the models CEPA/Ofwat submitted as part of the consultation;

ii) **Oxera**'s suite – i.e. the models submitted by Yorkshire to Ofwat;

iii) **EI's** suite – we have developed a new suite of models that "bridges the gap" between Ofwat's models and those developed by the rest of the industry. The method for this is set out in the subsection below.

We have looked at the range of efficiency scores in each suite to obtain a new range which takes account of all three suites.

In doing so, it is important to consider the ***choice of benchmark***. For PR14, Ofwat set its benchmark to the upper quartile (UQ) level of historical totex performance. However, in the PR19 methodology, Ofwat has indicated that the benchmark is likely to be more stringent with a view to benchmarking companies against the frontier company. Yorkshire's ambition is to achieve the UQ or above level of efficiency, so in this report we have primarily reported figures to the UQ score. However, we have also presented the catch-up efficiency to the frontier firm to inform on what adjustments need to be made to achieve this level.

We have ***consulted the entire suite*** and have not removed any outliers as they provide us with insight into the possible efficiency ranges that may occur if an alternative modelling approach was chosen. Hence, in our results we present the minimum and maximum ranges and also the average of all the models.

2.2 Developing new Economic Insight models

We have applied a consensus approach to variable selection. That is, we have started off with a 'base set' of variables which includes all the variables in Ofwat's models.

This set was then augmented by any variables that other companies have used in their models as part of the consultation submission. However, to avoid multi-collinearity issue, we have only included variables if it explains a “cost driver category” not fully captured in Ofwat’s models. Further, for the sake of parsimony, we have only included variables if it has been used by at least three other companies. Our approach is set out in Annex B.

The motivation for this approach is to bring together all the key cost drivers identified by the industry. Our method allows us to “bridge the gap” between Ofwat’s cost drivers and drivers identified by water companies.

Specifically, we have three stages:

» Stage 1: To develop our suite, we have first looked at the range of efficiency estimates from Ofwat’s models. Then we picked the **two models** that are at the extreme ends of the range. This gives us the best and the worst-case scenarios for Yorkshire as seen in Ofwat’s models.

» Stage 2: Then, we have added any **additional variables** identified at the ‘variable selection’ stage to the two models selected at Stage 1. Here we have added the additional variables one at a time to isolate and identify the effect of the new variables on Yorkshire’s efficiency scores. To this suite, we have also added two further models, which includes the base Ofwat models and **all** the variables identified by us.

» Stage 3: Our final set contains all the models developed by Ofwat, Oxera and Economic Insight. We have not filtered this suite as the purpose of this process is to obtain the best and the worst-case scenarios that Yorkshire is likely to face.

2.3 Alternative efficiency score for resources

From the analysis set out in Annex A, we conclude that the resources models give a very wide range of efficiency scores and are sensitive to various modelling choices. Therefore, we have developed an alternative way of estimating the efficiency score for water resources and bioresources.

In both the water and the wastewater models, we observe a gap in efficiencies in the service level and network plus models i.e. the service level efficiency is lower than the network plus level of efficiency. We assume that some of this gap is explained by inefficiencies in resources. Therefore, we have taken this gap and inflated it by the relative size of resources to obtain an efficiency estimate. Our method for calculating an alternative efficiency score for resources is set out in Annex B.

2.4 Use of cross-sector benchmarking

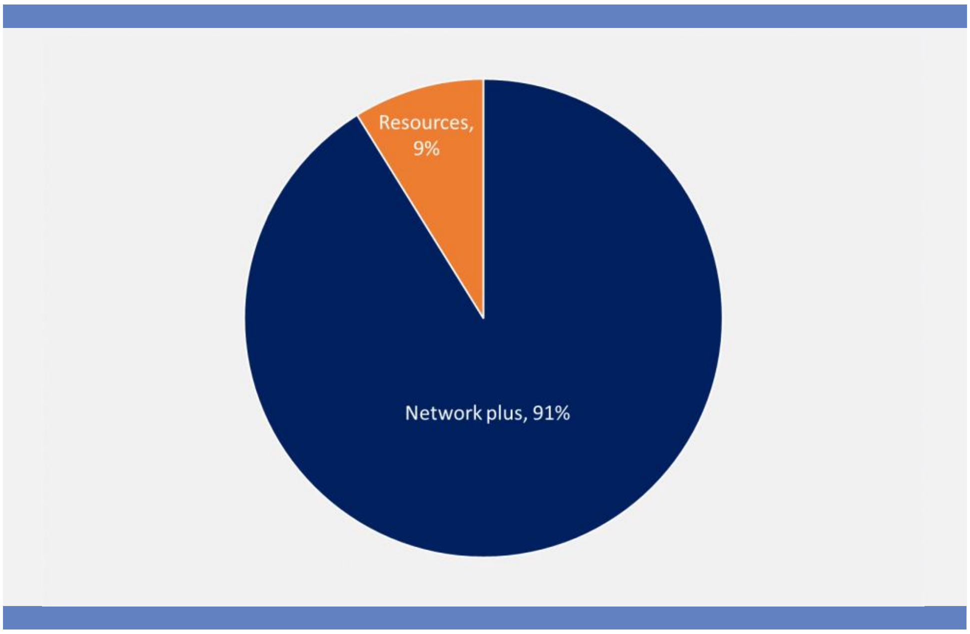
Due to the differences in modelling within-sector efficiency and undertaking a cross-sector analysis, results of the two are not directly comparable. As such, we have not combined the results of the two to obtain our efficiency estimates, but rather used the cross-sector work as a check for our within-sector work.

3. Water services results

In this section we set out our results from our water services econometric models.

Figure 5 illustrates the size of the price control areas in water services. Network plus constitutes 91% of water services costs while resources account for the remaining 9%. Hence, we expect efficiency estimates for Network Plus models to be similar to that of the service level models.

Figure 5: Price control splits for water services (2011/12 – 2016/17)



Source: Economic Insight

3.1 Water service level results

At the service level Ofwat has developed **12** models. In addition to Ofwat, **8 water companies** submitted models with a total of **43 unique variables.**

Across companies, there is some variation in the dependent variable used. Although, most companies have opted for botex models, some have also developed botex growth, totex and/or unit cost models. In our range of efficiency estimates below we have not split the models by the type of model; instead we have pooled them together to obtain a range which is inclusive of the different modelling choices.

We have identified **4 variables** that explain factors that may not be fully captured by Ofwat. They are:

- % of surface water treated;
- % DI from reservoirs;
- log of number of sources over distribution input; and
- dummy variable for the financial year 2016/17.

Figure 6 plots Yorkshire's catch-up efficiency score to the UQ score for all the models developed by Ofwat, Oxera and EI. The chart plots **28 models**, which includes Ofwat's 12 models, Oxera's 6 models and our hybrid suite containing 10 models. The figure shows that the catch-up efficiency is **0%** in most of the models. There are three instances where the catch-up efficiency is greater than 0%.

A note on the calculation of average efficiency:

The method applied to calculate the average efficiency score has important implications on Yorkshire's target. In cases where Yorkshire is less efficient or equal to the upper quartile score, the catch-up efficiency will be either zero or positive. However, in models where Yorkshire is more efficient the catch-up efficiency will be negative.

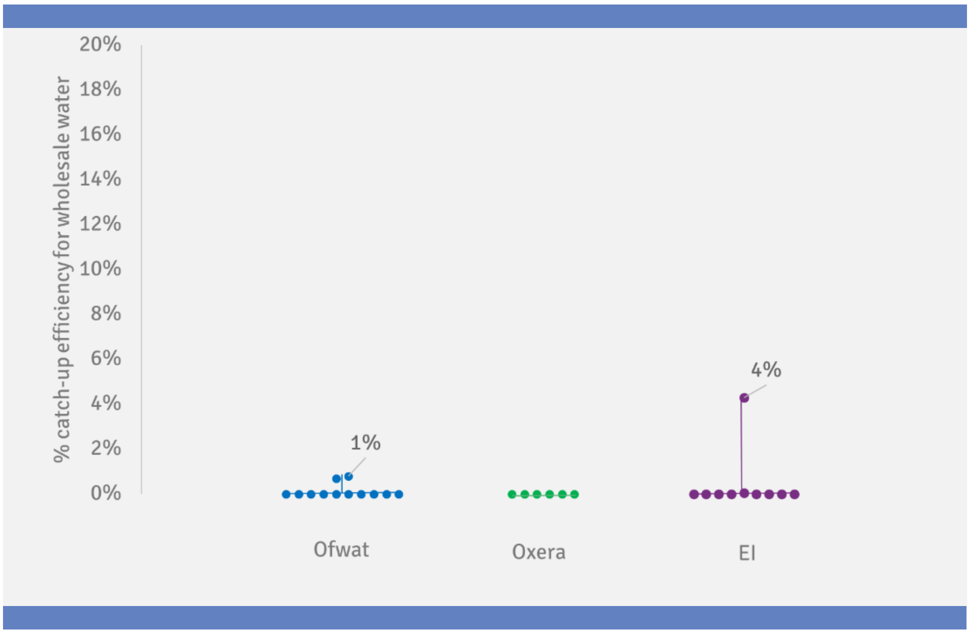
In this report, in models where Yorkshire appears to be more efficient we have rebased the efficiency scores from a negative figure to 0% before taking the average.

An implication of this method is that Yorkshire is not given the benefit of being ahead of the upper quartile score in some models, and therefore, the average efficiency score may overstate the level of inefficiency.

In our hybrid suite of models, we find in Ofwat's best case scenario model, the inclusion of the additional four variables does not change Yorkshire's rank. Yorkshire continues to be the frontier company in our analysis.

However, in Ofwat's model where Yorkshire performs least well, we find that Yorkshire's position is sensitive to the inclusion of the additional variables as the efficiency score ranges from 80% to 93% while the rank ranges between 3 and 7.

Figure 6: Catch-up efficiency to UQ for wholesale water



Source: Economic Insight

In the table below, we have summarised Yorkshire's efficiency score range to the UQ score and the frontier company across all three suites. As can be seen from Figure 6, the UQ range is 0% - 4% where the average is **0%**. However, when benchmarked to the frontier company, the range is much wider at 0% - 20% with an average of **6%.**

The efficiency range is a lot wider to the frontier firm because Yorkshire is within the UQ score in **24 out of the 28** models but it is the **frontier firm in 12 models.**

Table 1: Catch-up efficiency range and average for wholesale water

Benchmark	Range (min – max)	Average
UQ	**0% - 4%**	**0%**
Frontier	0% - 20%	6%

Source: Economic Insight

3.2 Price control level: network plus water

At the network plus price control level, Ofwat has developed **8 models**. In addition to this 10 water companies submitted models with a total of **65 unique explanatory** variables.

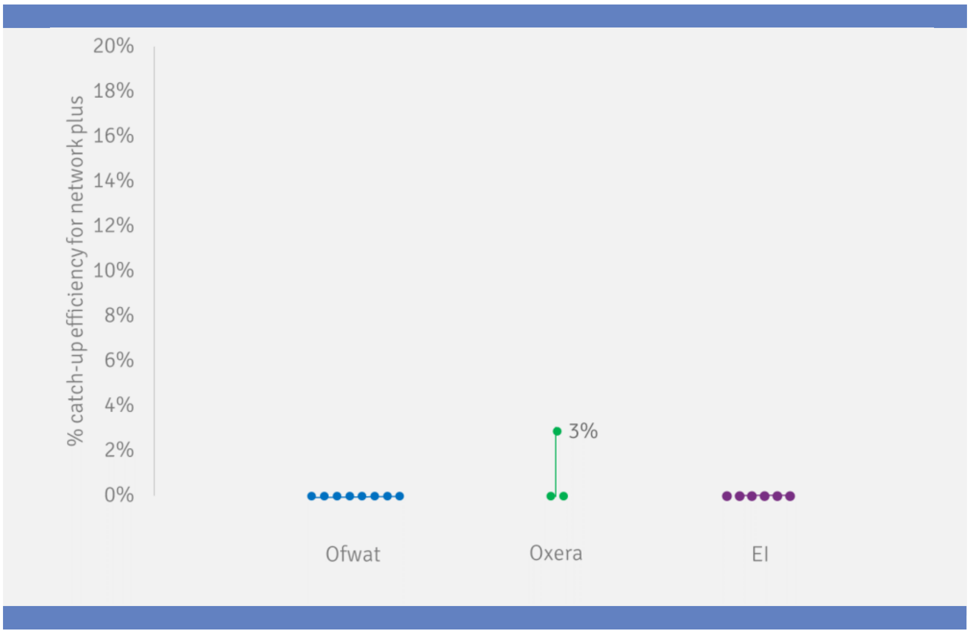
We find that the following two variables were used most frequently by water companies:

- % of distribution input from reservoirs
- year 2016/17 dummy

Figure 7 shows that Yorkshire's catch-up efficiency to the upper quartile score is **0%** in most of the models. The only exception to this is in one case where the score is 3%

in Oxera's model. Looking closely at Oxera's suite, we find that there is another model that is very similar to the model that gives us a higher efficiency score. The only difference between the two is the scale variable used. The model that gives the higher efficiency score uses population served as the scale variable, while the other model uses connected properties.

Figure 7: Catch-up efficiency to UQ for network plus water



Source: Economic Insight

Table 2 shows that the range to the UQ score is **0%-3%** with an average of **0%.** While the range to the frontier firm is **0%-15%** with an average of **5%.** Yorkshire performs well in all Ofwat's models; it is the frontier company in four out of eight, and ranked either second or third in the remaining four models.

Table 2: Catch-up efficiency range and average for network plus water

Benchmark	Range (min – max)	Average
UQ	**0% - 3%**	**0%**
Frontier	0% - 15%	5%

Source: Economic Insight

3.3 Price control level: resources

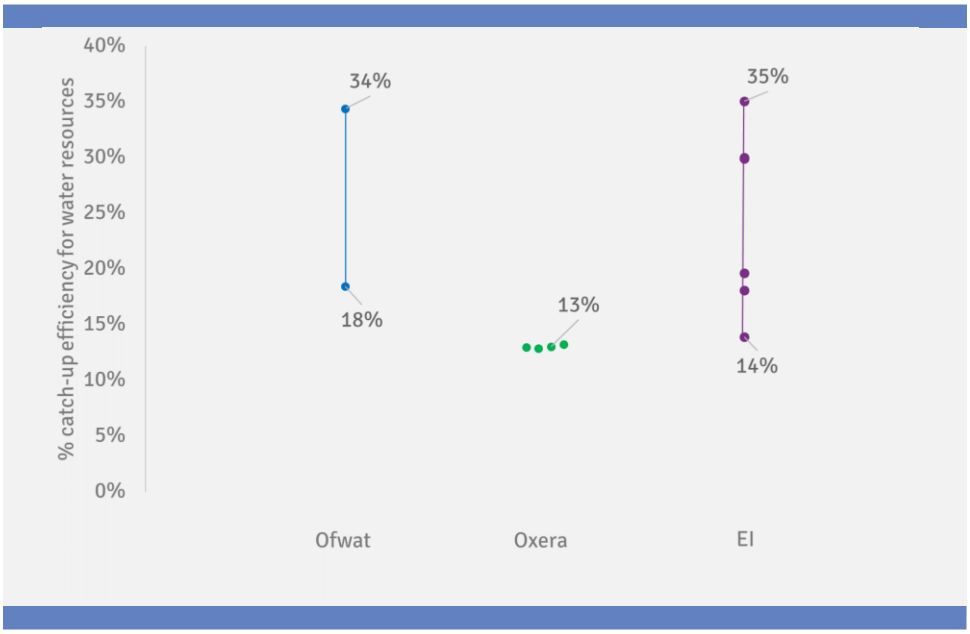
For the resources price control, Ofwat has adopted a parsimonious approach to modelling. They have developed only two models with two variables. In total, 4 other companies have chosen to submit their models for resources which include **23 unique variables.**

We have identified two variables used most frequently across companies that are outside of Ofwat's models, namely:

- % of distribution input from reservoirs
- % of distribution input from boreholes

Figure 8 shows that in Oxera's models, Yorkshire's efficiency score range is stable around 13%, however, in both Ofwat's suite and our suite, we find that the range shifts depending on the variable used.

Figure 8: Catch-up efficiency to UQ for water resources



Source: Economic Insight

Table 3 below shows that Yorkshire's efficiency range to the UQ firm is between **13% to 35%** with an average of **21%,** and to the frontier firm the range is **26% to 59%** with an average of **40%.** This is not surprising as across all the models, Yorkshire's rank ranges from 9 to 16. In our suite of models, we find that the inclusion of additional variables into Ofwat's models improves Yorkshire's rank in all cases.

Table 3: Catch-up efficiency range and average for resources

Benchmark	Range (min – max)	Average
UQ	**13% - 35%**	**21%**
Frontier	26% - 59%	40%

Source: Economic Insight

3.4 Alternative efficiency score for resources

From the above table, it is evident that resources models are highly sensitive to variables used in the models as the catch-up efficiency ranges from 13% to 35%. Annex A sets further details the limitations of these models. We have developed an alternative method that uses estimates from the water services and network plus models to arrive at an efficiency estimate for resources. As explained in the methodology, we have apportioned the gap between wholesale water and network plus as inefficiencies in resources and weighted it by the industry proportion for resources. Annex B sets out our method for calculating the alternative scores.

As shown in Table 4, the alternative efficiency estimate for water resources is **19%.**

Table 4: Alternative catch-up efficiency average for resources

Benchmark	Average
UQ	19%

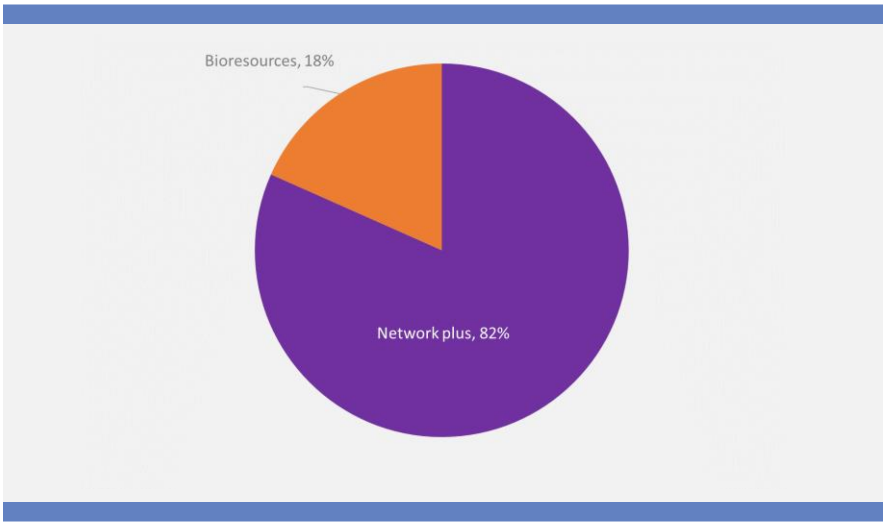
Source: Economic Insight

4. Wastewater results

In this section we set out our results from wastewater services econometric models.

Figure 9 illustrates the price control areas for wastewater. Bioresources accounts for a greater proportion of wastewater service level costs than resources for water service level costs.

Figure 9: Price control splits for wastewater (2011/12 – 2016/17)



Source: Economic Insight

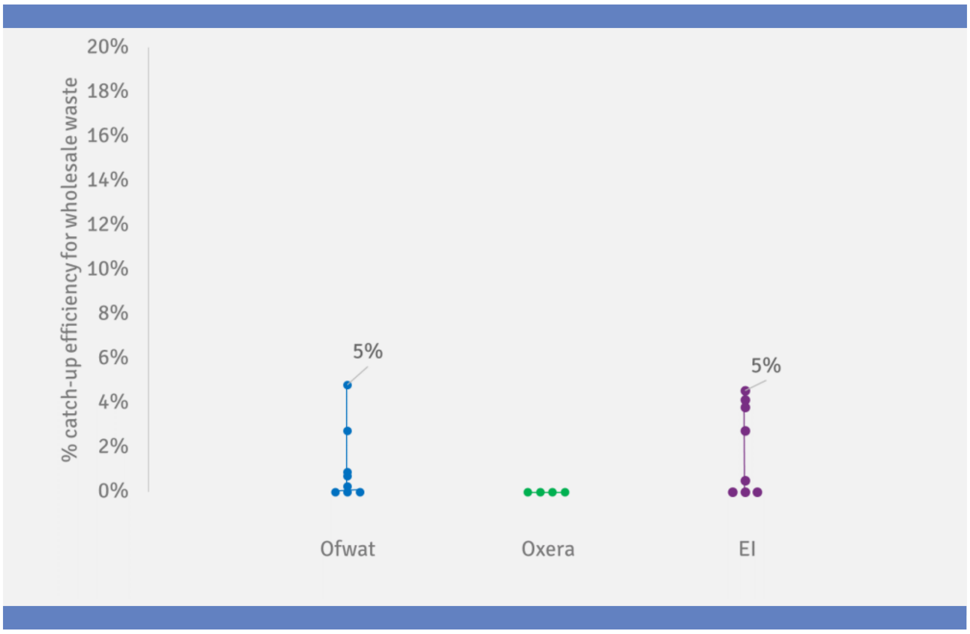
4.1 Wastewater results

For wholesale wastewater, Ofwat has developed 8 models. Eight water companies have submitted their models with a total of **40 unique variables.** In our models, we have included the following three variables that have been used by at least three other companies and are factors outside of Ofwat's models.

- % of area with more than 2000 people per km2
- % of load with BOD<10mg/L and amm<1mg/L
- ln (number of combined sewer overflows per km sewer length)

Figure 10 shows that Yorkshire's catch-up efficiency to the UQ score in most models is 0%. In Oxera's models it is stable at 0%, however in both Ofwat's suite and our suite it ranges from 0% to 5%.

Figure 10: Catch-up efficiency to UQ for wholesale wastewater



Source: Economic Insight

Table 5 shows that the efficiency range to the UQ firm is between **0% to 5%** with an average of **1%,** while the frontier firm is between **0% to 11%** with an average of **6%**.

Across the three suites we find that Yorkshire is within the UQ score in **12** out of the 20 models.

Table 5: Catch-up efficiency range and average for wastewater

Benchmark	Range (min – max)	Average
UQ	**0% - 5%**	**1%**
Frontier	0% - 11%	6%

Source: Economic Insight

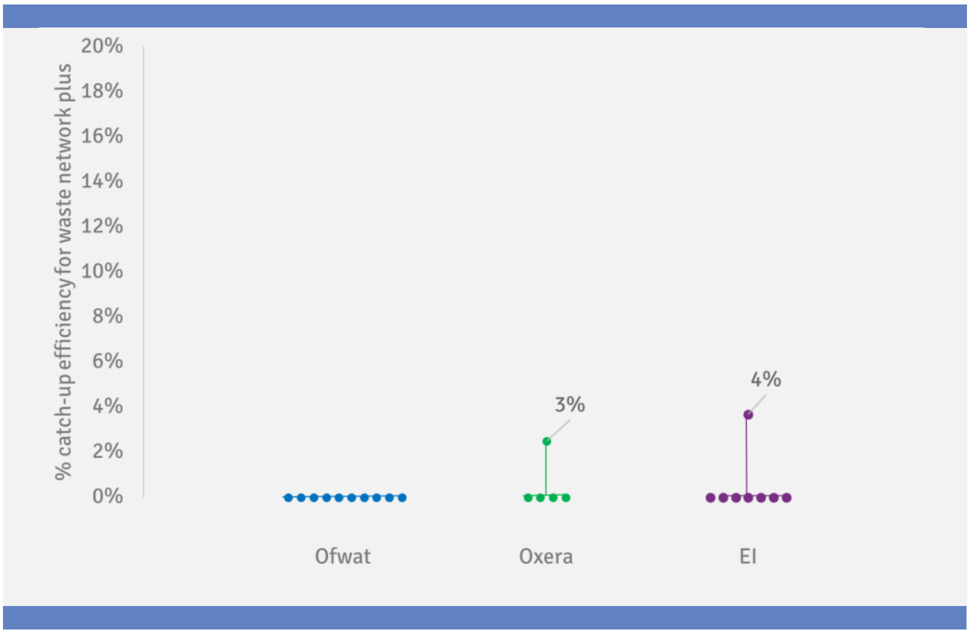
4.2 Price control level: network plus wastewater

For network plus wastewater Ofwat has developed 10 models. Eight other companies have submitted models with a total of **50 unique variables**. In our suite we have included the following variables:

- ln (pump capacity / length);
- % of sewers that are combined sewers; and
- dummy variables for the year 2012/13 – 2016/17.

Figure 11 shows that Yorkshire's catch-up efficiency to the UQ score for network plus is 0% in **21** out of the **23** models.

Figure 11: Catch-up efficiency to UQ for network plus



Source: Economic Insight

Table 6 shows that Yorkshire's efficiency range is between **0%** to **4%** to the UQ score with an average of **0%.** While the range to the frontier firm is between **0%** to **16%** with an average of **3%.**

Table 6: Catch-up efficiency range and average for network plus wastewater

Benchmark	Range (min – max)	Average
UQ	0% - 4%	0%
Frontier	0% - 16%	4%

Source: Economic Insight

4.3 Price control level: bioresources

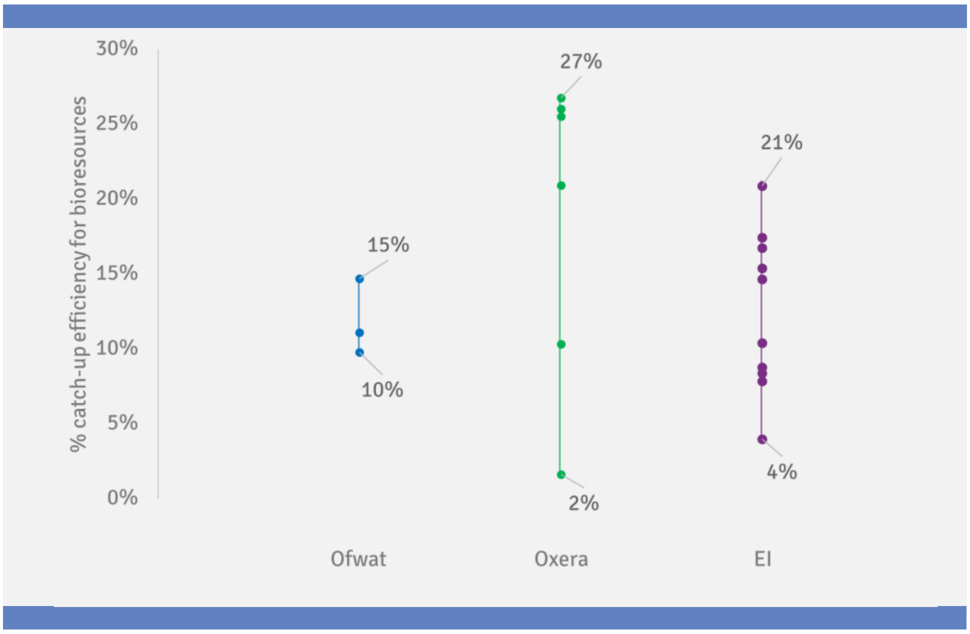
At the bioresources price control level, Ofwat has developed three models with parsimonious use of variables. Eight other companies have submitted their models with 41 unique variables.

We have identified the following four variables that have occurred recurrently and may not be fully captured in Ofwat's models:

- % tds treated by conventional or advanced anaerobic digestion;
- % of load treated in bands 1-3 works;
- % of sludge produced and treated at a site of STW and STC co-location; and
- % of area with less than 250 people per km2.

Figure 12 shows that the catch-up efficiency range for bioresources is large across all three suites. It is narrowest in Ofwat's suite and widest in Oxera's suite, however this may just be a function of the number of different models evaluated.

Figure 12: Catch-up efficiency to UQ for bioresources



Source: Economic Insight

Table 7 also shows that the efficiency score range is significantly larger than network plus and service level. The UQ efficiency range is between **2% - 27%** with an average of **14%** while the frontier efficiency range is between **12% - 34%** with an average of **23%.**

For bioresources, on average Yorkshire's rank is eight which explains the large efficiency score, however in two of Oxera's models we find that Yorkshire ranks 4th and 5th which explains the wider range.

Table 7: Catch-up efficiency range and average for bioresources

Benchmark	Range (min – max)	Average
UQ	**2% - 27%**	**14%**
Frontier	12% - 34%	23%

Source: Economic Insight

4.4 Alternative efficiency score for bioresources

The above table indicates that the bioresources models are unstable as the UQ score ranges from 2% to 27%. Annex A shows that the models appear unstable even when we look at only Ofwat's models. In the Annex, we have summarised company responses to Ofwat's models. Most companies have stated that the resources models may be unstable due to differences in cost allocation between companies. As resources is a small area, small difference in definition can create large scope for variation between companies.

We have developed an alternative method that uses estimates from the wastewater services and network plus models to arrive at an efficiency estimate for bioresources. As explained in the methodology, we have apportioned the gap between wholesale wastewater and network plus as inefficiencies in resources, and weighted it by the industry proportion for resources. We have then deflated this figure by the relative size of bioresources to botex. Breakdown of the calculation can be found in Annex B.

As shown in Table 8, the alternative efficiency estimate for bioresources is **10%.**

Table 8: Alternative catch-up efficiency average for bioresources

Benchmark	Average
UQ	**10%**

Source: Economic Insight

5. Cross-sector benchmarking

In this chapter, we will draw upon our cross-sector benchmarking research to i) evaluate whether it is feasible to benchmark Yorkshire against companies in other sectors, and if so, ii) whether this would imply a different efficiency target to the within sector estimates. We find that efficiency gains in the water sector are apace with other sectors. In wastewater, Yorkshire's average RUOE reductions are comfortably within the range of values calculated for wastewater and other sectors. For Yorkshire's water operations, the value calculated is lower relative to that of water companies and other sectors, however, this is likely due to Yorkshire's place as an upper quartile firm resulting in the opportunity for significant further cost reductions dwindling. These values therefore imply that a more stringent efficiency target than within-sector estimates is not appropriate.

5.1 Background and objectives

Ofwat expects companies to make a step change in cost efficiency over the upcoming price control, and there is a strong expectation for companies to "**look beyond their boundaries"** to achieve this.[4] Specifically, in its final methodology for PR19, Ofwat stated that they aim to set an efficiency challenge for water companies based on both a comparative assessment within the sector, and by using relevant information regarding the performance of other sectors in the wider economy.

In keeping with this objective, we have looked to gauge the level of efficiency improvements across sectors over a set period of time, to understand whether efficiency gains in the water sector are apace with those achieved by comparable regulated sectors, and if there is therefore scope to set a more stretching efficiency target for Yorkshire Water than within sector estimates suggest.

In order to do this, we have:

[4] *'Delivering Water 2020: Our final methodology for the 2019 price review', Ofwat, December 2018*

- Conducted a review of existing literature looking to establish trends in real unit operating expenditure (RUOE) efficiency over time across sectors, and
- Conducted our own analysis of changes in RUOE over the period 2011-12 to 2016-17, across the electricity transmission and distribution sectors, airports, rail and telecoms sectors.

The remainder of this chapter is organised as follows:

- We summarise our ***findings of the literature review***. Much of this literature relates to an earlier time period compared to our analysis, and thus helpfully supplements our analysis and reveals important trends in cost efficiency over time.
- The ***results*** of our RUOE analysis are then presented and discussed.
- We ***discuss the challenges and limitations of benchmarking RUOE*** across sectors, including issues regarding the comparability of the RUOE efficiency estimates.
- Finally, we discuss ***whether the results of the analyses imply a different efficiency target*** to the within sector estimates.

5.2 Literature review

Prior to conducting our own RUOE analysis, we looked to review existing literature across a range of regulated sectors. This was to both build a view of the longer-term trends in cost efficiency gains across sectors; and to obtain an understanding of the challenges faced when conducting this analysis. Details of the literature reviewed is presented in Annex C.

From existing literature, the evidence suggests that over a reasonably long-time period (10+ years), RUOE savings of around 0% to 5% per annum have been achieved in other regulated infrastructure sectors. There is also some evidence to suggest that size of RUOE savings have fallen over time. A summary of our findings is presented in the table below.

Figure 13: Summary of the range of RUOE reductions per year from literature reviewed

Sector	Time period	Range per year	Average per year
Electricity transmission	1990/91 – 2010/11	2.5% to 6.8%	4.7%
Electricity distribution	1990/91 – 2009/10	2.5% to 7.7%	5.1%
Gas networks	1986/87 – 2012/13	2.1% - 7.5%	4.6%
Airports	1980 - 2012	-1.2% to 1.6%	0.2%
Rail	1995/96 – 2010/11	3.1% to 5.5%	4.3%

Telecoms	1983 - 2007	-1.1% to 10.3%	4.6%
Range	**1980 – 2012/13**	**-1.2% to 10.3%**	**0.2% to 5.1%**

Source: Economic Insight

The review shows that average RUOE reductions vary significantly ***between*** sectors, with the electricity distribution sector being estimated to achieve the highest average RUOE reduction of 5.1% per annum, while the airport sector is reported to have achieved average RUOE reductions of only 0.2% per annum.

Additionally, it is worth noting that the estimated efficiency gains ***within*** each sector vary significantly over the literature reviewed. Notably, some studies concluded that the airport sector is becoming less efficient, with real unit operating costs rising.[5] However, other studies analysing a similar time frame suggest that the opposite is true, and cost efficiency is in fact increasing.[6] Similarly, there is a 10-percentage-point difference between the highest and lowest estimates for average RUOE reductions per annum across the telecommunications sector.

5.3 RUOE analysis

In this section we detail the sample size, methodology and results of our own RUOE analysis.

5.3.1 Sample size

We analysed data on operating costs for the period 2011-12 to 2016-17 for firms in the water, wastewater, electricity distribution and transmission, airports, rail and telecommunications sectors to gather a range of average RUOE efficiency scores. A table summarising the sample used is included below.

Table 9: Details of sample

Sector	Time period	Number of companies	Total observations
Water	2011/12 – 2016/17	18	104
Wastewater	2011/12 – 2016/17	10	60
Electricity distribution	2011/12 – 2016/17	14	84
Electricity transmission	2011/12 – 2016/17	1	6
Airports	2011/12 – 2016/17	2	12
Rail	2011/12 – 2016/17	1	6

[5] '*Scope for efficiency gains at Heathrow, Gatwick and Stansted Airport*', CEPA (2013).
[6] '*Regulatory reform and productivity growth in the UK's public utilities*' Bishop and Thompson (1992).

Telco	2011/12 – 2016/17	1	6

Source: Economic Insight

5.3.2 Methodology

To calculate the average RUOE efficiency for each sector, we divided the total operating costs, adjusted for inflation using the RPI index, by an appropriate scale variable. The year-on-year percentage change in RUOE was then calculated per firm over the time period 2011-12 to 2016-17. The average of these percentage changes was then taken across firms in each sector.

The advantage of benchmarking ***percentage changes in unit costs*** as opposed to the ***actual level of unit costs***, is that it accounts for intrinsic differences between sectors which lead to a different proportion of a firm's costs being within management control. Some firms will have a naturally higher level of unit cost than others, owing to the service they provide. However, firms in different sectors may be able to adopt efficient management practices which enable them to achieve similar unit cost reductions.

5.3.3 Results

The results of our cross-sector RUOE analysis are presented below.

Table 10: Results of cross-sector RUOE analysis

Sector	Scale	Average RUOE efficiency
Water	Total properties connected	1.92%
Yorkshire Water (water)	Total properties connected	0.65%
Wastewater	Total number of properties	2.70%
Yorkshire Water (wastewater)	Total number of properties	3.51%
Electricity Distribution	Number of customers	2.23%
Airports	Terminal passengers handled	2.02%
Rail	Passenger km travelled	1.43%
Telco	Openreach total physical lines	5.08%

Source: Economic Insight

We omitted electricity transmission from the results owing to it being a significant outlier.

As shown above, efficiency gains across sectors as a whole over 2011-12 to 2016-17 range from **1.43% to 5.08%.** The rail sector proves to achieve the lowest average efficiency gains over the period, while, in line with findings from the literature review, the telecommunications sector achieves the highest average annual reductions. The water and wastewater sectors sit comfortably within this range, achieving average per annum efficiency gains of **1.92% to 2.70%** respectively.

Looking to Yorkshire Water's performance, the average RUOE reduction per annum for the water business is **0.65%**; below the average in the water sector itself, as well as compared to other sectors.

On the other hand, with regards wastewater, Yorkshire strongly outperforms relative to firms within the sector, achieving an average annual RUOE reduction of **3.51%** per annum. This rate of unit operating cost reduction is only surpassed by the telecommunications sector.

5.4 Implications for Yorkshire Water

In order to derive implications from the above results for Yorkshire Water's efficiency target, there are two important factors that need to be borne in min.

- **First, changes in RUOE measure a combination of catch-up efficiency, dynamic efficiency and no doubt other changes, including for example quality of service.** Therefore, a relatively small change in RUOE may be indicative of an already efficient firm who has realised the catch-up efficiency savings available to it. be because catch-up efficiency gains have been exhausted, or because dynamic efficiency is low or some other reason. It is hard to know.

- **Second, changes in RUOE are sensitive to several analytical choices / judgments.** These include the choice of:

  - scale variable;
  - inflation measure;
  - time period;
  - quality adjustments; and
  - economies of scale adjustments.

With these factors in mind and the general difficulty in making comparisons across sectors, our view is that average RUOE efficiency results should not be used in a mechanistic way to derive Yorkshire's efficiency target, but can perhaps help inform or cross-check the results of within-sector benchmarking.

- With regards **wastewater**, Yorkshire's average annual RUOE reduction is comfortably within range achieved by other sectors, and at the upper end of that achieved by other wastewater companies. This implies that there is little scope to apply a more stretching efficiency target to this portion of Yorkshire's operations.

- For Yorkshire's **water** business, the average annual RUOE reduction is low compared to within-sector values, and to that of other sectors. Although at first glance this might imply that there is scope for improvement here, Yorkshire performs above the upper quartile when it comes to water services. It is therefore more likely that the low value is indicative of the limited opportunity for Yorkshire to make further cost savings in this area.

6. Annex A: Review of Ofwat's models

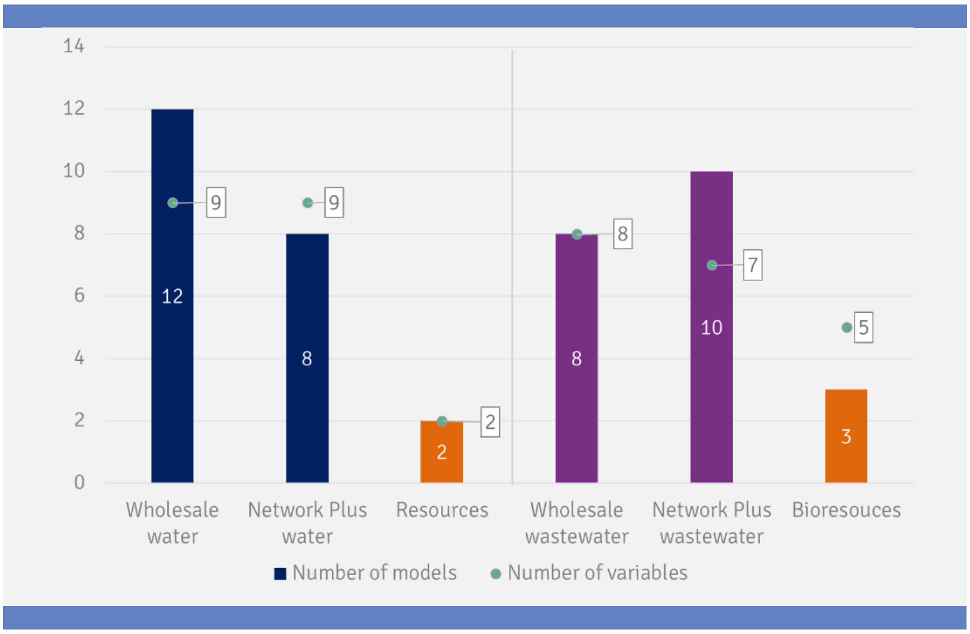
In this section, we evaluate models published by Ofwat with a focus on the robustness of the resources and bioresources model. We find that models at the lower levels of aggregation are less reliable than models at the higher levels of aggregation. Most water companies have supported this view in their review of Ofwat's models.

Figure 1 illustrates the number of models estimated by Ofwat and the number of unique variables used in each area. It is clear from the chart that Ofwat has published the fewest models in resources and bioresources and has adopted a parsimonious approach to variable use.

This section is set out as follows:

- evaluation of the range of scores **within** a model**;**
- evaluation of Yorkshire's efficiency scores **across** models;
- summary of responses submitted by water companies to Ofwat, on the appropriate levels of aggregation.

Figure 14: Models estimated by Ofwat



Source: Economic Insight

6.1 Evaluation of the range of scores within a model

To assess Ofwat's models we first looked at the range of efficiency scores ***within*** a model. Here we examine the difference between the efficiency scores predicted for the most and the least efficient company in a given model. Models with large gaps between their predictions may indicate that relevant cost drivers have not been included and/or that there are limitations in modelling the corresponding cost. This in turn would mean that some companies may be over or under compensated in their allowance due to differences in relative efficiency. This may limit the trust and confidence that can be placed on these models to set an appropriate efficiency challenge for companies.

We have applied the following criteria to assess Ofwat's models:

- **Criterion 1**: The difference between the largest efficiency score and the smallest efficiency score within a model.

- **Criterion 2**: The difference between the second largest efficiency score and the second smallest efficiency score. This criterion tests whether the gap persists even after any 'outliers' have been removed.

Figure 15 and Figure 16 plot the above criteria across Ofwat's service and price control models for water and wastewater.

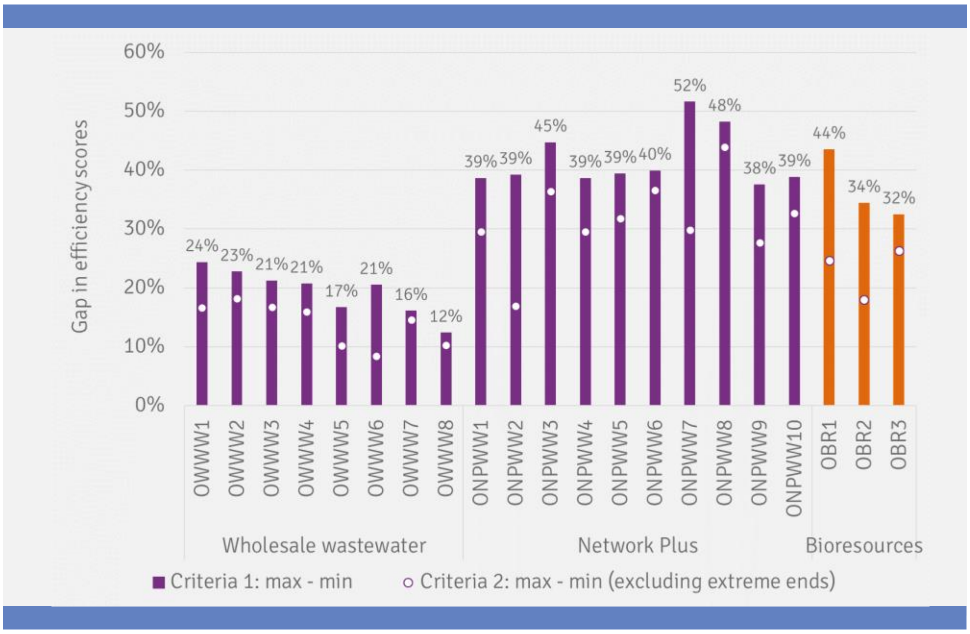
In the water models, the average gap between the largest and the smallest efficiency score is 47% in wholesale water, 48% in network plus and 124% in resources. The variation in the resources models indicates that the relevant cost drivers have not been fully captured or there are inherent difficulties in modelling these costs. This continues to persist even when we do not account for the efficiency scores at the extreme ends of the range.

In the wastewater models, the average gap between the largest and the smallest efficiency score is 19% in wholesale wastewater, 42% in network plus and 37% in bioresources. Here, the gap in the resources models departs from the range obtained in the wholesale wastewater models but is within the range that we see in the network plus models.

Figure 15: Criteria 1 and 2 in water models

Source: Economic Insight

Figure 16: Criteria 1 and 2 in wastewater models



Source: Economic Insight

6.2 Evaluation of Yorkshire's efficiency scores across models

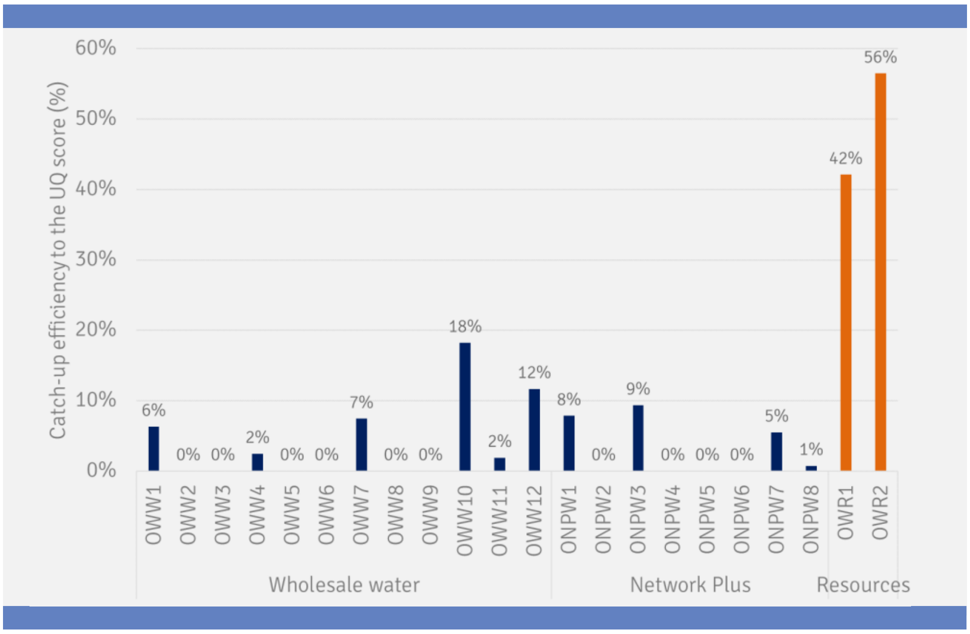
For the second part of our analysis, we evaluate what Ofwat's modelling choices mean for Yorkshire. Specifically, we examine Yorkshire's efficiency scores ***across*** the service level and price control areas. Figure 17 and Figure 18 illustrates Yorkshire's efficiency score to the frontier firm.

In the water models, Figure 17 shows us that the Yorkshire's catch-up efficiency to the frontier firm in wholesale water is between 0% to 18%, in network plus it is between 0% to 9% and in resources it is between 42% to 56%.

Figure 5 shows us that Yorkshire's catch-up efficiency to the frontier firm in wholesale water is between 2% to 11%, in network plus it is between 0% to 7% and in bioresources it is between 15% to 30%.

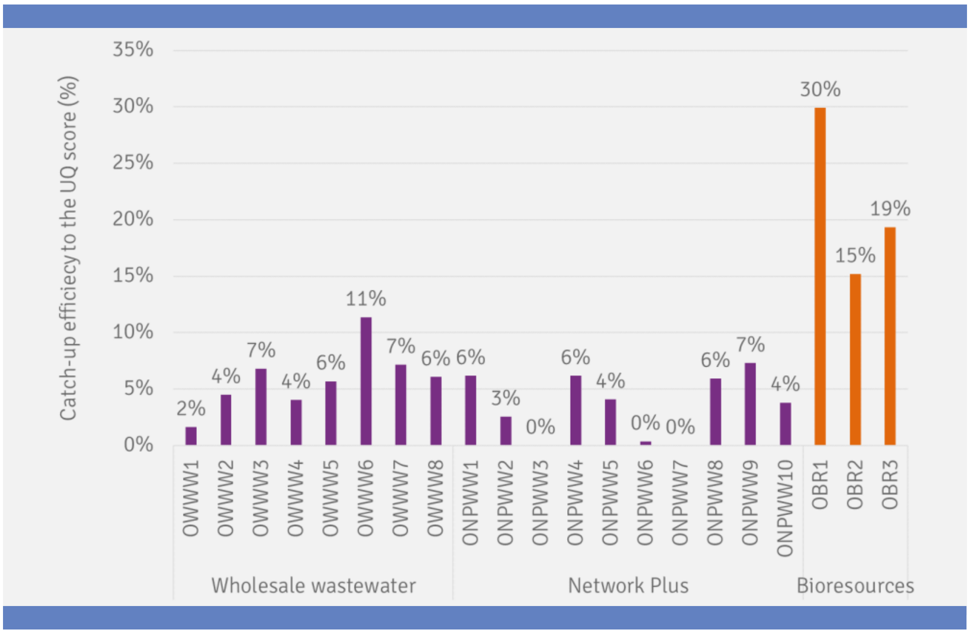
In both the business areas, we find that the resources and the bioresources scores depart from the predictions at the service level and the network plus price control level.

Figure 17: Catch-up efficiency to the frontier firm for Yorkshire – water models



Source: Economic Insight

Figure 18: Catch-up efficiency to the frontier firm for Yorkshire – wastewater models



Source: Economic Insight

6.3 Response on the appropriateness of the different levels of aggregation by other companies

In this section we summarise key ideas conveyed in the consultation responses submitted by various companies.

6.3.1 Yorkshire's response to the consultation

- Yorkshire has evaluated the wholesale models by looking at the gap in the efficiency scores between the least and the most efficient company within a model. They find that models at the lower levels of aggregation are less robust than models at the higher levels of aggregation. This issue is more pronounced in water than in wastewater.

- They question the suitability of these models for cost assessment purposes. As such, they state that models at the lower levels of aggregation could still be part of the final suite but that greater weight should be placed on models at higher levels of aggregation.

6.3.2 Summary of the key points made by other water companies

- Most responses suggest that the aggregated models are more stable and work better statistically. Some have stated that the industry planning decisions are taken at the service level and so this is the more appropriate level of aggregation. Many have pointed out that the wide ranges in water resources models indicate that the variance cannot be entirely attributable to managerial inefficiency. As such, companies have suggested that more weight should be attached to models at the higher levels of aggregation, while using models from the lower levels as "cross-check" on results obtained from other methods.

- In contrast, some companies have stated that the lower levels are more appropriate because at the higher levels, it becomes harder to design a single model that encompasses all the key cost drivers associated with the broad range of activity.

- Some responses have explained that the wide range in efficiency scores in the resources models could be due to accounting differences between companies. As water resources is a small price control area, small differences in definition can create large scope for variation between companies.

- Further, some companies have suggested that the aggregation of granular models can result in infeasible efficiency scores, as it does not account for the operational trade-offs across the value chain. For instance, if a company has predominantly borehole sources then it achieves high levels of efficiency in the treatment models, but, this would imply that the company would have to spend more on pumping surface water which would result in the company appearing less efficient in the resources models. That is, it is not possible to be UQ on resources (companies with predominantly surface water sources) and simultaneously UQ on treatment (companies with predominantly borehole sources). Hence, modelling them separately, would imply unachievable benchmarks of efficiency for companies with a greater proportion of a particular source.

- There is some disagreement on how models at the lower levels of aggregation should be modelled. Some companies have appreciated Ofwat's parsimonious approach to modelling resources stating that due to the inherent difficulties in modelling resources and bioresources this is probably the best approach. Others have suggested that the simplicity of these models implies that it is unlikely that the estimated variances represent inefficiency entirely. Consequently, the inclusion of these models in a wider set of models may introduce some degree of noise. They state that due to the complex nature of resources and bioresources operations, more involved models are required so that variations at the price control levels are appropriately captured.

- We note that Welsh Water have suggested two alternative methods for calculating inefficiencies in resources. First, they suggest that the wholesale water models could be used to calculate total allowed expenditure and then this could be sub-divided pro rata according to the respective shares of water resources and network plus. Second, they suggest that a figure for water resources could be inferred by taking the difference between the results obtained from water and network plus models.

Table 11: Key excerpts from company responses to Ofwat's models[7]

Company	Discussion on the levels of aggregation
Affinity Water	We observe that the more aggregated models seem to work better statistically and suggest that the use of such models will avoid issues that might be created by **accounting allocation issues**, which we believe remain an issue, particularly within the network plus services, where the accounting boundaries have been subjected to less attention than the boundary between resources and network plus.
Anglian Water	Regarding water resources models: In our two cost modelling reports, published in September 2017 and March 2018, we and our academic advisors have **highlighted issues with regard to data quality, definition and separability for this modelled activity.** These initial models suggest that Ofwat has also found it difficult to model cost at this level of disaggregation. However, it is notable that almost all the other models presented by companies are superior to those presented by Ofwat, in that they appear to use more appropriate drivers of water abstraction botex.
Bristol Water	In many cases the models presented in the consultation appear to perform better using our criteria on more aggregated data rather than separated into separate expenditure subcategories. This is particularly apparent for water resources and the sub-modelling within retail. The evidence suggests that modelling at wholesale total and retail total cost level produces better models. We think this is because **industry planning decisions are taken across wholesale water and residential retail and therefore this is the right level to measure efficiency**, particularly between water resources and water treatment and between retail bad debt and other retail costs. The logic of selecting simple disaggregated models is not apparent from the data, because the economic, operational and engineering logic is likely to be, for "botex" models in particular, at a wholesale total and retail total level. For Water Resources modelling, we think there is a case for further consideration of what costs are included and excluded from the cost modelling. There is logic in third party and abstraction charges to be excluded from the modelling, but with increasingly diverse cross-regional buying and selling of water there are other similar costs which are embedded in charges not excluded from the modelling that may be apparent. This may be a logical reason not to use disaggregated modelling as these factors are far less material at a wholesale total level.
Northumbrian Water	We believe that the aggregated models (both medium and high levels) are more stable and reliable than the disaggregated ones and that Ofwat should give greater weight to the aggregated models. In our view it is not surprising that more granular models are **less stable as**

[7] *Cost Assessment for PR19 – a consultation on econometric cost modelling, Ofwat, Responses section, (2018).*

	there is more scope for variation between companies in cost allocation or in the physical assets associated with narrowly defined sub service categories.
Portsmouth Water	We note less confidence in the individual business unit models of Water Resources, Water Treatment, and Treated Water Distribution. The range of estimated efficiency scores in Water Treatment and Water Resources models are particularly wide, with Treated Water Distribution models being more comparable to Network Plus and Wholesale Water models. Given wide range in the estimated residuals, it cannot be the case that the **variance is entirely attributable to managerial inefficiency.** The quality of the models considered in the final suite of models should inform the appropriate level of efficiency challenge for the industry.
Sutton and East Surrey Water	The objective should be to model costs at the level of aggregation of the price control and there should therefore be a model for water resource costs only. However, the two proposed water resource models are currently **failing to fully reflect the differences in companies' assets and the resulting replacement, maintenance and operational costs**. If this cannot be resolved then we suggest that water resource costs are assessed in a different way.
Southern Water	It is important to acknowledge that the aggregation of granular models can result in infeasible efficiency frontier as, depending on how this is undertaken, the approach may not appropriately account for operational trade-offs and cost allocation decisions. For example, if a company achieves high levels of treatment efficiency through larger treatment centres, this would likely also require the company to incur higher pumping and sewer network costs. Modelling these components separately and making efficiency adjustments at each level would not account for these operational trade-offs and would imply unachievable benchmarks of efficiency. We also note that certain aspects of the value chain are particularly challenging to modelling cost performance statistically. In addition to raw water distribution, we find the water resources and water treatment models estimate too large a range of residuals across the industry to be considered credible. **Given the general simplicity of these models, it is unlikely that the estimated variances represent inefficiency appropriately**. If these models are considered for inclusion in a final suite of models, care should be taken in how they are combined to form an aggregate position and due account should be taken of the quality of these models when determining an appropriate level of efficiency challenge.
South Staffs Water	We have identified that in general the water resources models perform less well than network plus or BOTEX models (in terms of the estimated range of residuals). This is most likely because **water resources is a relatively small price control compared to network plus**, and likely to be more sensitive to cost allocation differences between companies at the margins. Because

	of this we think that it would be inappropriate to set the water resources price control on the basis of a water resource model alone, and that a wider set of information should be taken into account, including examining a top down allocation between water resources and network plus, as well as information from wholesale BOTEX modelling. However we think that broadly speaking the majority of models submitted for water resources are reasonable and would be appropriate to use in a triangulated approach as a sense check to a top down allocation approach.
South East Water	The disaggregated models that Ofwat and companies have developed are helpful from a model development perspective, to assess cost claims and cross-check estimates from aggregate modelling. However, the water resources and water treatment models estimate a large range of residuals across the industry to be deemed credible. Given the general simplicity of these models (in terms of the cost drivers considered; functional form; estimation approach), it is **unlikely that the estimated variances represent inefficiency entirely**. If these models are considered in a final suite of models, care should be taken in how they are combined to form an aggregate position and the quality of these models in determining an appropriate level of efficiency challenge.
Severn Trent Water	At the same time, we would note that if the characteristics of water resources are not being captured (because of complexity, idiosyncrasy, etc.), then the inclusion of water resources in a wider set of costs to be modelled **may introduce a significant degree of 'noise'** into the process. This has implications for the reliance that should be put on model results, and while that 'noise' may be relatively diluted when aggregate water wholesale models are being considered, this suggests that significantly more caution may be merited when seeking to use water resources plus models.
South West Water	Wide range of efficiency estimates / application of an upper quartile (UQ) benchmark to a model with omitted variables - water resources models suggest an implausibly wide range of company outcomes with a total range of over 160% for both models. By comparison the maximum range of efficiency scores across wholesale water models submitted across all companies is 100%. All but two wholesale water models give a range of less than 70%, less than half that of the water resources models. Given the possibility that a large proportion of the error term is down to omitted variables in the model, we would consider a UQ benchmark based on these cost assessment models to be an inappropriate target to apply to companies. Not only would such a target likely over-state the scope of efficiency improvements to be made, there is a real likelihood that high performing companies would be penalised within such a model

	Trade-offs across the value chain - we think that modelling the water resource part of the value chain in isolation is problematic due to ignoring the trade-offs with water treatment and the wide efficiency score that result from the modelling. Due to the ignored trade-offs between parts of the value chain, **the estimated efficiencies do not relate solely to efficiency and would result in 'cherry picking'.** That is, it is not possible to be UQ on resources (companies with predominantly surface water sources) and simultaneously UQ on treatment (companies with predominantly borehole sources)
Thames Water	As the value chain is aggregated into higher and higher levels, it becomes more difficult to design a single model to encompass all of the key cost drivers associated with the very broad ranges of activity included. This is implicit in some of the criticisms set out by the CMA in the past. For example, treatment, distribution and resource activities are very different, each with distinct cost drivers – combining these into one model to predict an efficient cost is very challenging. This challenge is exacerbated where the reference data set relates to a limited time period, during which many cost drivers vary little, if at all (as is the case here). Our conclusion, therefore, **is that the primary modelling should take place at a disaggregated level**, with higher level models at the network plus level and total service level operating as cross-checks.
Welsh Water	As we indicated earlier we have concerns about the water resources models as a group, and in particular the implausibly wide range of residuals that they produce. We think this probably reflects, amongst other factors, the **high degree of substitution between water resources and elements of "network plus".** We are attracted by the suggestion of using wholesale water models, which are generally of higher quality, to set a figure for total allowed expenditure which can then be sub-divided pro rata according to the respective water resources and network plus shares of a company's expenditure forecasts Another possibility that could be examined is to infer a figure for water resources expenditure by taking the difference between the results obtained from wholesale water and network plus models. However, this could produce perverse results if the model for wholesale water were very different from that for network plus: we think it would be useful, in this case, if the two shared several features in common, including the principal explanatory variables. In any event we think it could be **risky to rely upon the results of any of the water resources models**. However, it could be useful to examine them as a "cross-check" upon results obtained from other approaches. The usefulness of disaggregated models as cross-checks holds for other areas as well.

Wessex Water	Care needs to be given when considering at what level to aggregate model costs. At too aggregate a level you end up with too wide an array of cost drivers to fully explain costs, particularly when modelling distribution and treatment costs together. For example, the complexity of treatment could be a credible driver of treatment costs but would have no impact on distribution costs. At too disaggregated a level there are **issues around cost allocation,** and setting a false efficiency frontier taking the efficient company from each set rather than considering the performance of companies at a combined level. The latter risks are easier to mitigate by simply considering company level performance over all models when setting efficiency frontiers. We therefore favour a more disaggregated assessment and combining areas where there are common cost drivers or material concerns over cost allocation, such as water resources and treatment, and in running "cross check" models at a more aggregate level.
Yorkshire Water	Greater weight should be given to models at more aggregated levels. That is not to say that disaggregated models should not be included as part of the final suite of assessment models, only that the influence of these models on the final assessment should be appropriately weighted to reflect the fact that models at a more aggregate level have performed generally more robustly than disaggregated models.

Source: Excerpts from the responses published on Ofwat's website

7. Annex B: Methodology and results

In this section, we describe our method and results in detail, our consensus approach to model development and calculating efficiency scores. We then set out the econometric results from our models. Finally, we present Yorkshire's efficiency score results from the triangulation of the Ofwat, Oxera and EI models.

7.1 Introduction

For PR19, Ofwat requested water companies to submit their econometric models with a view to developing high quality models such that efficiency targets can be set with more confidence. As part of this process, 13 water companies submitted their suites of model. In total, Ofwat received 103 water models and 120 wastewater models. Alongside this, they developed their own suite of 48 water models and 39 wastewater models.

In addition to the large number of models submitted, companies also used a wide range of variables to explain costs. For instance, for water network plus, **45 models** were developed with a total of **65 unique variables.** As such, we have applied a **"consensus approach"** to model development, which involves creating a suite of models that captures key modelling choices made by the industry.

This focused approach encompasses Ofwat's current thinking, along with previously published Yorkshire models (as developed by Oxera) and key variables developed by other companies. Our aim here is to obtain a range of efficiency estimates which are robust to range of modelling choices.

This annex is set out as follows:

- triangulated suite of models;
- variable selection process;
- the three stages of developing the EI suite of models;
- results from the EI suite;
- and the efficiency score results.

7.2 Triangulated suite of models

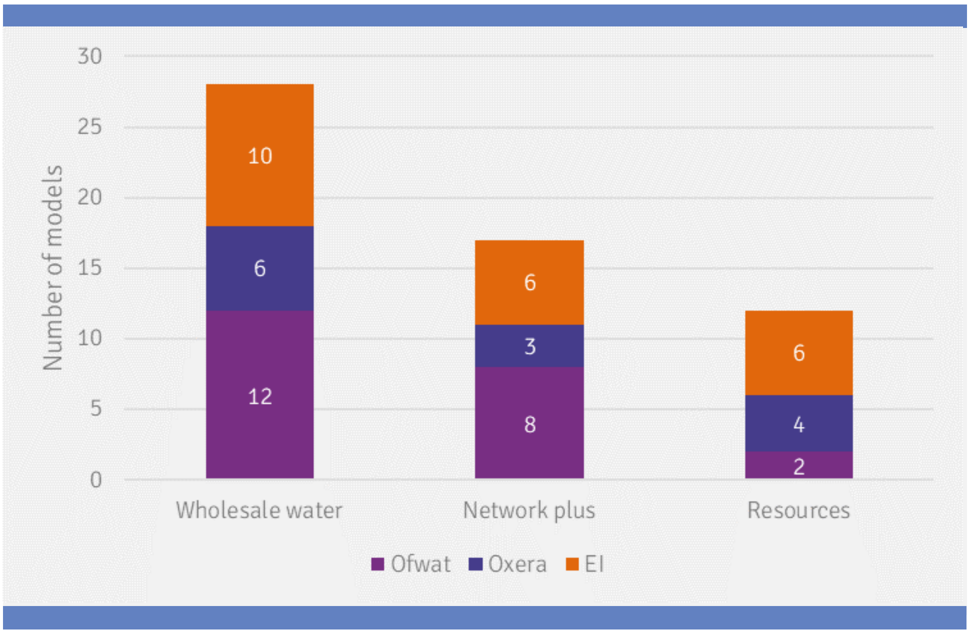
We have applied a **"consensus approach"** to model development. Most companies have submitted suites of models for each area with some publishing up to 12 models in some areas. These suites of models help in 'dampening' the effect of any 'outlier' models. However, it is difficult to objectively determine the 'right' suite of models. Hence, we have decided to derive our efficiency ranges by triangulating key suites of models.

For this report, we have triangulated the following suites of models:

I. Ofwat's suite - this includes all the models CEPA/Ofwat submitted as part of the consultation;
II. Oxera's suite – i.e. the models submitted by Yorkshire to Ofwat
III. EI's suite – this contains a new suite of models which contain Ofwat's models that have been modified to include variables that have been most frequently used by other companies. Our suite "bridges the gap "between Ofwat's models and the models developed by the rest of the industry.

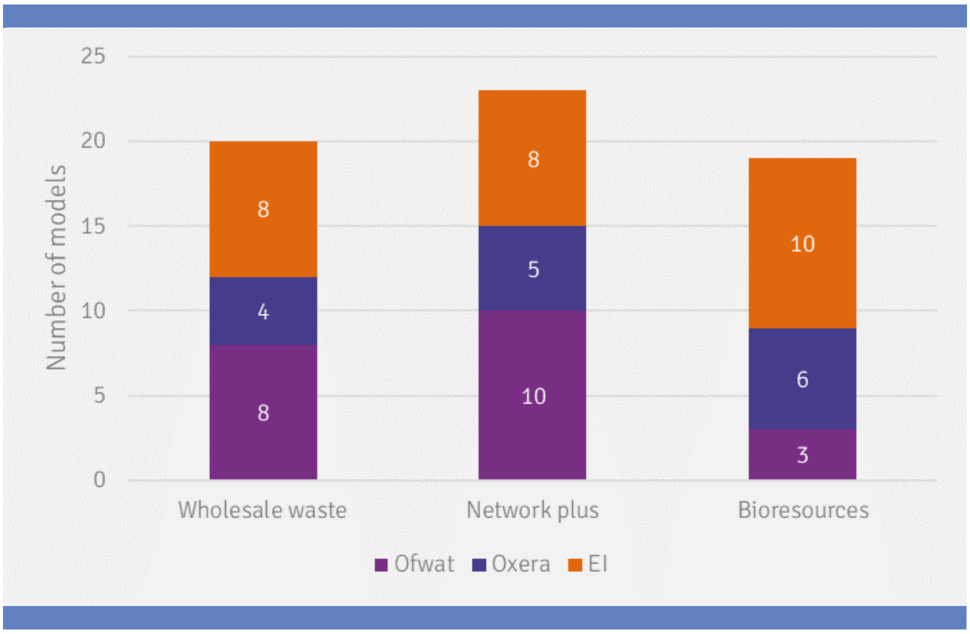
Figure 19 and Figure 20 illustrate the number of models that we have evaluated to estimate the range of efficiency scores. From the charts, we can see that Ofwat has developed the fewest number of models in resources and bioresources. When calculating the scores, we have attached equal weight to each of the individual models within these suites.

Figure 19: Number of water models



Source: Economic Insight

Figure 20: Number of wastewater models



Source: Economic Insight

7.3 Variable selection process

Table 12 and Table 13 presents the number of unique variables used in Ofwat's models and the number of unique variables considered by water companies. The table shows us that up to **65 variables** have been used to explain network plus water and up to **50 variables** have been used to explain network plus wastewater. It is clear from the table that Ofwat has adopted a more parsimonious approach to modelling, as they have used only 2 variables to model water resources and 5 to model bioresources.

Table 12: Number of unique variables in water models

	Number of unique variables used in Ofwat's models	Number of unique variables used by water companies which are not in Ofwat's models	Total unique variables
Wholesale water	9	34	**43**
Network Plus	9	56	**65**
Resources	2	21	**23**

Source: Economic Insight

Table 13: Number of unique variables in wastewater models

	Number of unique variables used in Ofwat's models	Number of unique variables used by water companies which are not in Ofwat's models	Total unique variables
Wholesale wastewater	8	32	**40**
Network Plus	7	43	**50**
Bioresources	5	36	**41**

Source: Economic Insight

We have developed the following criteria to obtain the most relevant variables to include in our models.

- Criterion 1 - consensus variable:
  The variable must be used in the models presented by at least three companies[8]. Our rationale for using three companies is two-fold: i) to obtain a concentrated set of variables which reflects the industry's view of key cost drivers and ii) to narrow down the pool of variables as there are many variables that have been used by at least two companies.

- Criterion 2 – new factor:
  The cost driver must be a factor that's not fully captured in Ofwat's models. For instance, if Ofwat has incorporated a density measure (e.g. properties / mains) then even if another density measure (e.g. DI / properties) appears frequently, we have not included it in our suite of models as density is already explained in Ofwat's models. Another reason for not including two factors of the same nature is to avoid issues relating to multicollinearity which can lead to coefficients becoming unstable (where small changes in one variable can result in large changes to the estimated regression coefficients) and the standard errors can get inflated.

Together these criteria give us a new set of variables that are key drivers (as recognised by the industry) and explains factors that may not be fully explained in Ofwat's models. Figure 21 provides an illustrative example of the application of these criteria.

Figure 21: Illustrative example of the variable selection process

New variable	1 Frequency	2 Is the factor explained in Ofwat's models?	To include in the EI suite?
X1	4	No	✓
X2	3	No	✓
X3	3	Yes	✗
X4	2	Yes	✗

Source: Economic Insight

[8] We are aware that Oxera has submitted models for Yorkshire and Southern Water. The set of variables used in the two submissions are similar but not identical. To avoid double counting, where a variable is used in both company's models, we have treated it as a single observation.

7.3.1 Set of variables

Table 14 and Table 15 lists the set of new variables that met both the criteria.

Table 14: New variables incorporated in EI water models

	New variables
Wholesale water	- surface water treated / total water treated (%) - % DI from reservoirs - ln (number of sources / DI - year 2016 dummy
Network Plus	- % DI from reservoirs - year 2016 dummy
Resources	- % DI from reservoirs - % DI from boreholes

Source: Economic Insight

Table 15: New variables incorporated in EI wastewater models

	New variables
Wholesale wastewater	- % of area with more than 2,000 people per km2 - % of load with BOD<10mg/L and amm<1mg/L - ln(number of combined sewer overflow per km sewer)
Network Plus	- ln(pump capacity / length) - % of sewers that are combined sewer - year 2013 dummy - year 2014 dummy - year 2015 dummy - year 2016 dummy - year 2017 dummy
Bioresources	- % tds treated by conventional or advanced anaerobic digestion - % load treated in band 1- 3 works - % of sludge produced and treated at a site of STW and STC co-location - % of area with less than 250 people per km2

Source: Economic Insight

7.4 Developing the EI suite of models

The aim of incorporating the different suites of models is to obtain a range of efficiency estimates for Yorkshire that is robust to different modelling choices. Essentially, our suite of models is designed to stress test Ofwat's results by incorporating key variable choices made by the rest of the industry.

There are three stages to developing our suite of models. They are as follows:

- Stage 1: Identify Ofwat's models in which Yorkshire obtains the highest and the lowest efficiency score. This gives us the best and the worst-case scenarios for Yorkshire.

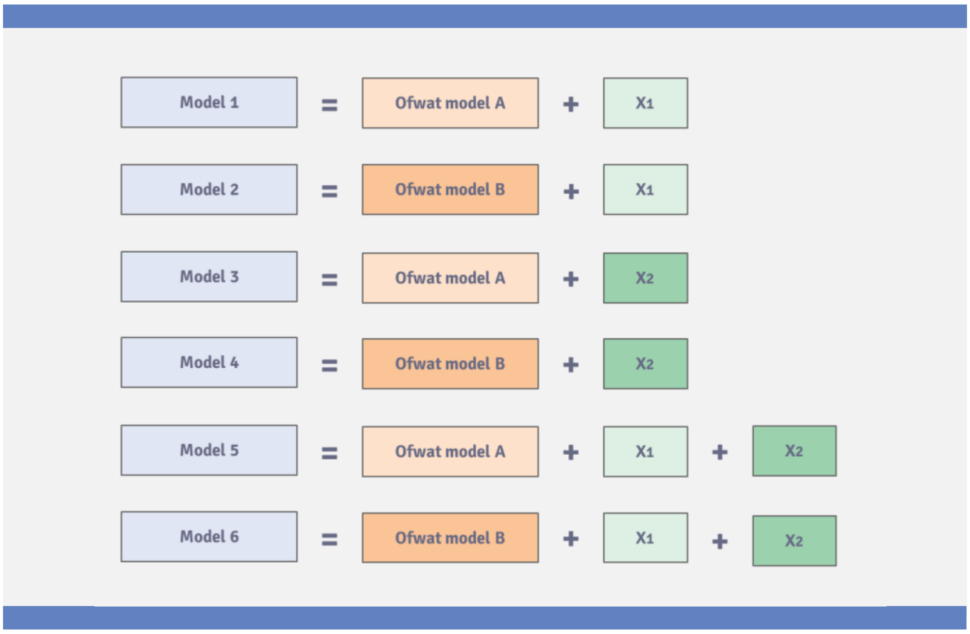
- Stage 2: Identify variables that explain cost drivers not fully captured in Ofwat's models and most frequently used by the rest of the industry.

- Stage 3: Add these variables into Ofwat's two "outermost" models. These are added one at a time and all together. Adding them one at a time allows us to isolate the effect of each variable and avoids major multicollinearity issues. However, in the last set of models we have included all the new variables together, to identify how sensitive the ranges are to a combination of all the variables.

The figure below illustrates these three stages. Suppose Ofwat's model A and model B give us Yorkshire's maximum and minimum efficiency scores and suppose variable X1 and X2 have been identified as variables that are not in Ofwat's models and most frequently used by water companies. Then each of these variables have been added individually and together to model A and model B, giving us a total of 6 models.

Note that this set of models does not contain all the variables that Ofwat has used as it only considers the "outermost" models. Also, note that one could obtain a different range if we combine the omitted models and new variables.

Figure 22: Illustrative example of EI model development



Source: Economic Insight

7.5 EI suite results

In this section we summarise our results from the water and the wastewater models.

7.5.1 Water services results

Water services results

Table 16 sets out our results for wholesale water. For water services Ofwat has developed 12 models. In these models, Yorkshire's rank ranges from 1 to 6 while the efficiency score to the UQ score ranges from 0% to 1%. In our suite, Yorkshire's rank ranges from 1 to 7 and the catch-up efficiency to the UQ score ranges from 0% to 4% and to the frontier firm the range is between 0% to 20%. That is, our models imply a wider range and higher efficiency scores to the UQ score.

We have added four new variables to Ofwat's models. Out of the four variables, % distribution input from reservoirs and the 2017 year dummy are significant. Unsurprisingly, we find the VIF measures which tests for multicollinearity to be highest in the models EI W9 and EI W10 as these include all Ofwat's variables, along with our new set.

Water network plus results

For water network plus Ofwat developed 8 models. In Ofwat's models, Yorkshire's rank ranges from 1 to 3 while the catch-up efficiency in Ofwat's models to the UQ score is 0%. In our suite, the rank ranges from 1 to 5. Hence, as Yorkshire is more efficient than the notional UQ firm, we find that in all the models the catch-up efficiency to the UQ score is 0%.

The inclusion of the additional variables does not affect the range to the UQ score estimated by Ofwat. These results are presented in
Table 17.

Water resources results

Ofwat has taken a parsimonious approach to modelling water resources. They have developed two models for water resources and have used only two explanatory variables. In Ofwat's models, Yorkshire's rank ranges from 11 to 16 with a catch-up efficiency to the UQ score ranging from 18% to 34%.

In our suite, Yorkshire's rank ranges from 9 to 15 and the efficiency score ranges from 14% to 35% to the UQ score and from 30% to 59% to the frontier firm. This implies, that our suite of models has a wider range than Ofwat's models. Our results are presented in Table 18.

Table 16: Wholesale water models

Model ID	Ofwat OWW5	Ofwat OWW12	EI W1	EI W2	EI W3	EI W4	EI W5	EI W6	EI W7	EI W8	EI W9	EI W10
Dependent variable	----- ln (wholesale water base costs) -----											
ln (connected properties)	1.037*** {0.000}		1.029*** {0.000}		1.044*** {0.000}		1.038*** {0.000}		1.039*** {0.000}		1.071*** {0.000}	
ln (lengths of main)		1.082*** {0.000}		1.059*** {0.000}		1.081*** {0.000}		1.080*** {0.000}		1.084*** {0.000}		1.076*** {0.000}
% mains length refurbished and relined	0.247** {0.014}	0.165 {0.173}	0.240*** {0.005}	0.205* {0.061}	0.252** {0.018}	0.173 {0.154}	0.263*** {0.007}	0.220** {0.042}	0.277*** {0.009}	0.204 {0.109}	0.359*** {0.001}	0.279*** {0.005}
ln (booster pumping stations per lengths of main)	0.392*** {0.006}		0.342** {0.022}		0.360*** {0.007}		0.378** {0.011}		0.390*** {0.006}		0.098 {0.552}	
ln (service reservoirs and water towers per lengths of main)		0.165 {0.360}		0.096 {0.607}		0.161 {0.372}		0.098 {0.568}		0.159 {0.363}		-0.023 {0.886}
% of lengths of mains laid or refurbished 1981	-0.005 {0.197}	-0.008* {0.094}	-0.006* {0.081}	-0.009** {0.022}	-0.005 {0.282}	-0.009* {0.080}	-0.006 {0.178}	-0.011** {0.012}	-0.006 {0.184}	-0.009* {0.087}	-0.008** {0.025}	- 0.012*** {0.000}
% of water treated in water treatments in complexity levels 3-6	0.003 {0.130}		0.002 {0.340}		0.003** {0.030}		0.002 {0.286}		0.003 {0.127}		0.003** {0.021}	
ln (average pumping head for water resources plus)		0.231* {0.065}		0.142 {0.251}		0.228* {0.069}		0.235** {0.036}		0.220* {0.080}		0.209** {0.019}
ln (weighted average density)		0.290*** {0.001}		0.245*** {0.002}		0.279*** {0.003}		0.274*** {0.001}		0.283*** {0.001}		0.385*** {0.000}
% DI from reservoirs			0.002* {0.077}	0.003* {0.075}							0.003** {0.043}	0.002 {0.199}
ln (number of sources / DI)					0.038 {0.569}	-0.019 {0.791}					0.214** {0.022}	0.326*** {0.005}
% surface water treated / total water treated							0.001 {0.529}	0.002 {0.144}			0.003 {0.101}	0.006** {0.011}
year 2017 dummy									0.087*** {0.002}	0.094*** {0.004}	0.111*** {0.001}	0.125*** {0.001}
Constant	5.780*** {0.000}	6.139*** {0.000}	5.699*** {0.000}	6.680*** {0.000}	5.561*** {0.000}	6.192*** {0.000}	5.715*** {0.000}	5.899*** {0.000}	5.729*** {0.000}	6.167*** {0.000}	4.158*** {0.000}	5.020*** {0.000}

Model ID	Ofwat OWW5	Ofwat OWW12	EI W1	EI W2	EI W3	EI W4	EI W5	EI W6	EI W7	EI W8	EI W9	EI W10
R2 adjusted	0.974	0.969	0.976	0.972	0.974	0.969	0.974	0.971	0.975	0.97	0.98	0.978
VIF (max)	1.254	2.533	1.403	2.953	1.725	3.676	1.591	2.597	1.257	2.562	4.218	7.041
Reset test	0.047	0.019	0.097	0.084	0.005	0.008	0.052	0.07	0.044	0.012	0	0
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	107	107	107	107	107	107	107	107	107	107	107	107
YKY rank	1	6	1	3	1	5	1	3	1	6	1	7
YKY catch-up to frontier	0%	12%	0%	8%	0%	10%	0%	7%	0%	13%	0%	20%
YKY catch-up to UQ score	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%

Table 17: Network Plus water models

Model ID	Ofwat ONPW6	Ofwat ONPW7	EI W11	EI W12	EI W13	EI W14	EI W15	EI W16
Dependent variable	----- ln (network plus water base costs) -----							
ln (lengths of main)	1.037***	1.044***	1.039***	1.027***	1.042***	1.048***	1.044***	1.031***
	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}
% of mains length refurbished and relined	0.232**	0.172	0.241**	0.191*	0.270**	0.220*	0.282**	0.240**
	{0.038}	{0.166}	{0.022}	{0.073}	{0.024}	{0.090}	{0.013}	{0.034}
ln (booster pumping stations per lengths of main)	0.416***		0.321*		0.394**		0.289	
	{0.007}		{0.064}		{0.010}		{0.104}	
ln (service reservoirs and water towers per lengths of main)		0.036		-0.056		0.023		-0.07
		{0.836}		{0.751}		{0.889}		{0.687}
% of mains length laid or refurbished after 1981	-0.006	-0.010**	-0.007*	-0.011**	-0.007	-0.010**	-0.008*	-0.011**
	{0.123}	{0.047}	{0.078}	{0.017}	{0.107}	{0.042}	{0.067}	{0.016}
ln (average pumping head for water treatment)		0.111***		0.100***		0.111***		0.099***
		{0.004}		{0.002}		{0.003}		{0.002}
% of water treated in water treatments in complexity levels 3-6	0.002		0.002		0.002		0.002	
	{0.201}		{0.380}		{0.187}		{0.384}	
ln (density)	1.064***		0.970***		1.033***		0.930***	

Model ID	Ofwat ONPW6	Ofwat ONPW7	EI W11	EI W12	EI W13	EI W14	EI W15	EI W16
	{0.000}		{0.000}		{0.000}		{0.000}	
ln (weighted average density)		0.221***		0.196**		0.215***		0.189**
		{0.007}		{0.011}		{0.009}		{0.014}
% DI from reservoirs			0.002	0.003**			0.002	0.003**
			{0.206}	{0.012}			{0.188}	{0.010}
year 2017 dummy					0.094***	0.126***	0.102***	0.129***
					{0.001}	{0.000}	{0.002}	{0.000}
Constant	5.736***	7.074***	5.738***	6.969***	5.707***	7.004***	5.707***	6.897***
	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}
R2 adjusted	0.974	0.968	0.971	0.969	0.976	0.972	0.976	0.969
VIF (max)	2.287	1.641	3.182	2.533	1.403	2.953	2.045	3.162
Reset test	0.476	0.025	0.021	0.019	0.097	0.084	0.004	0
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	107	107	107	107	107	107	107	107
YKY rank	1	3	1	2	1	4	1	2
YKY catch-up to frontier	0%	5%	0%	6%	0%	5%	0%	6%
YKY catch-up to UQ score	0%	0%	0%	0%	0%	0%	0%	0%

Table 18: Water resources models

Model ID	Ofwat OWR1	Ofwat OWR2	EI W17	EI W18	EI W19	EI W20	EI W21	EI W22
Dependent variable	----- ln (water resources base costs) -----							
ln (lengths of main)	1.026***	1.069***	0.971***	1.000***	1.001***	1.045***	0.974***	0.999***
	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}
ln (average pumping head water resources)		0.163		0.097		0.168*		0.089
		{0.139}		{0.209}		{0.080}		{0.286}
% DI from reservoirs			0.007***	0.007**			0.008***	0.008**
			{0.008}	{0.016}			{0.007}	{0.021}
% DI from boreholes					-0.003	-0.003	0.001	0.001
					{0.161}	{0.131}	{0.526}	{0.664}
Constant	1.938**	0.808	2.432**	1.734	2.398**	1.243	2.314**	1.707
	{0.019}	{0.460}	{0.015}	{0.138}	{0.017}	{0.264}	{0.020}	{0.147}
R2 adjusted	0.889	0.894	0.92	0.921	0.896	0.902	0.92	0.921
VIF (max)	1	1.259	1.08	1.408	1.061	1.314	1.791	1.924
Reset test	0.562	0.62	0.001	0.003	0.011	0.001	0.002	0.005
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	107	107	107	107	107	107	107	107
YKY rank	11	16	10	13	9	15	10	14
YKY catch-up to frontier	42%	56%	33%	44%	45%	59%	30%	41%
YKY catch-up to UQ score	18%	34%	18%	30%	14%	35%	20%	30%

7.5.2 Wastewater services results

Wastewater services results

For wastewater, Ofwat has developed 8 models. In these models, Yorkshire's rank ranges from 3 to 7. Yorkshire range to the frontier firm ranges from 2% to 11%.

In our suite, Yorkshire's rank ranges from 2 to 9. The efficiency score ranges from 0% to 5% to the UQ score and to the frontier firm it ranges from 0% to 11%.

In our models, we have augmented Ofwat's models with three new variables. These are: % of area with more than 2,000 people per km2, % of load with tight ammonia and BOD consents and the number of combined sewer overflows per sewer length. Table 19 presents are results for wastewater services.

Wastewater Network Plus

For Wastewater Network Plus, Ofwat has published 10 models. In most of these models, Ofwat has used only two or three explanatory variables. In Ofwat's models Yorkshire's rank ranges from 1 to 3. The catch-up efficiency to the UQ score is 0% in all the models.

In our models, Yorkshire rank ranges from 1 to 4 with an efficiency score range of 0% to 4% to the UQ score and from 0% to 16% to the frontier firm. The range implied by our suite of models is higher than Ofwat's suite. These results are presented in Table 20.

Bioresources

For bioresources, Ofwat 's suite contains 3 models. Yorkshire is ranked 8th in all these models. The efficiency range to the UQ score is between 11% to 15% and to the frontier firm it is between 15% to 30%.

In our suite, Yorkshire's rank ranges from 8 to 10. The catch-up efficiency to the UQ score ranges from 4% to 21% and to the frontier firm it ranges from 13% to 34%. The range to the UQ score in our suite of models is much more varied than Ofwat's suite.

Out of the four new variables that we have added, two are insignificant in our models. Our results are given in Table 21.

Table 19: Wholesale wastewater models

Model ID	Ofwat OWWW1	Ofwat OWWW6	EI WW1	EI WW2	EI WW3	EI WW4	EI WW5	EI WW6	EI WW7	EI WW8
Dependent variable	----- ln (wholesale wastewater base costs) -----									
ln (properties)		0.976*** {0.000}		1.013*** {0.000}		0.927*** {0.000}		0.831*** {0.000}		0.754*** {0.000}
ln (load)	0.877*** {0.000}		0.848*** {0.000}		0.694*** {0.000}		0.780*** {0.000}		0.600*** {0.000}	
% lengths replaced post 2001	-0.013** {0.013}		-0.017*** {0.002}		-0.015*** {0.000}		-0.016** {0.023}		-0.015*** {0.008}	
% load treated in STWs bands 1-3	0.034* {0.079}	0.066*** {0.000}	0.036* {0.061}	0.064*** {0.000}	0.027* {0.094}	0.063*** {0.000}	0.033* {0.087}	0.071*** {0.000}	0.024* {0.069}	0.056*** {0.000}
ln (density)		1.317*** {0.001}		1.342*** {0.001}		1.243*** {0.001}		1.610*** {0.000}		1.338*** {0.000}
% load from trade effluent customers		0.087*** {0.001}		0.069* {0.052}		0.088*** {0.001}		0.132*** {0.000}		0.098*** {0.002}
% of area with more than 2,000 people per km2			0.003* {0.071}	-0.002 {0.115}					-0.001 {0.426}	-0.003** {0.014}
% of load with BOD<10mg/L and amm<1mg/L					1.132*** {0.000}	0.249 {0.536}			1.320*** {0.004}	0.852*** {0.005}
ln (num of combined sewer overflow per km sewer)							-0.128 {0.183}	-0.167*** {0.000}	-0.104 {0.157}	-0.132*** {0.003}
Constant	8.253*** {0.000}	-0.944 {0.402}	8.573*** {0.000}	-1.482 {0.158}	10.485*** {0.000}	0.058 {0.977}	9.142*** {0.000}	-0.723 {0.508}	11.407*** {0.000}	1.81 {0.140}
R2 adjusted	0.946	0.963	0.951	0.966	0.962	0.963	0.953	0.971	0.967	0.976
VIF (max)	2.35	2.913	2.625	3.153	5.708	9.519	4.483	6.071	8.494	13.101
Reset test	0.001	0.002	0	0.017	0.007	0	0	0.043	0.011	0.663
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	60	60	60	60	60	60	60	60	60	60

Model ID	Ofwat OWWW1	Ofwat OWWW6	EI WW1	EI WW2	EI WW3	EI WW4	EI WW5	EI WW6	EI WW7	EI WW8
YKY rank	3	7	6	2	3	7	5	9	5	2
YKY catch-up to frontier	2%	11%	11%	5%	7%	11%	10%	9%	5%	0%
YKY catch-up to UQ score	0%	3%	4%	0%	0%	4%	3%	5%	1%	0%

Table 20: Network Plus wastewater models

Model ID	Ofwat ONPW7	Ofwat ONPW8	EI WW9	EI WW10	EI WW11	EI WW12	EI WW13	EI WW14	EI WW15	EI WW16
Dependent variable	----- ln (network plus wastewater base costs) -----									
ln (volume)	0.746***		0.795***		0.583***		0.750***		0.689***	
	{0.000}		{0.000}		{0.000}		{0.000}		{0.000}	
ln (sewer length)		0.738***		0.793***		0.596***		0.736***		0.762***
		{0.000}		{0.000}		{0.000}		{0.000}		{0.000}
% lengths of sewer laid post 2001	-0.015**	-0.018	-0.015**	-0.017	-0.021***	-0.022	-0.017**	-0.019	-0.020***	-0.019
	{0.018}	{0.166}	{0.016}	{0.211}	{0.004}	{0.123}	{0.014}	{0.161}	{0.004}	{0.202}
ln (pump capacity / length)			0.218***	0.226***					0.177***	0..211***
			{0.006}	{0.001}					{0.000}	{0.000}
% of sewers that are combined sewer					-0.242**	-0.186			-0.148**	-0.033
					{0.020}	{0.182}			{0.045}	{0.808}
year 2013 dummy							-0.055	0.117***	-0.042	0.113***
							{0.104}	{0.007}	{0.357}	{0.008}
year 2014 dummy							0.03	0.121***	0.037	0.116**
							{0.517}	{0.010}	{0.501}	{0.014}
year 2015 dummy							-0.042	0.080*	-0.032	0.075
							{0.349}	{0.089}	{0.556}	{0.123}
year 2016 dummy							0.034	0.130***	0.033	0.121**
							{0.436}	{0.004}	{0.539}	{0.012}
year 2017 dummy							0.132***	0.194***	0.110*	0.176***

Model ID	Ofwat ONPW7	Ofwat ONPW8	EI WW9	EI WW10	EI WW11	EI WW12	EI WW13	EI WW14	EI WW15	EI WW16
							{0.005}	{0.002}	{0.052}	{0.007}
Constant	9.432***	11.802***	8.583***	11.045***	10.945***	12.752***	9.372***	11.730***	9.617***	11.192***
	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}	{0.000}
R2 adjusted	0.882	0.836	0.924	0.881	0.915	0.848	0.887	0.836	0.944	0.88
VIF (max)	1.015	1.01	1.1	1.104	2.195	3.063	1.71	1.704	2.827	4.245
Reset test	0.032	0	0.003	0.055	0	0.01	0.132	0.004	0.002	0.435
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	60	60	60	60	60	60	60	60	60	60
YKY rank	1	3	1	3	1	4	1	3	1	3
YKY catch-up to frontier	0%	6%	0%	15%	0%	15%	0%	6%	0%	16%
YKY catch-up to UQ score	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%

Table 21: Bioresources models

Model ID	Ofwat OBR1	Ofwat OBR2	EI WW17	EI WW18	EI WW19	EI WW20	EI WW21	EI WW22	EI WW23	EI WW24	EI WW25	EI WW26
Dependent variable	----- ln (bioresources base costs) -----											
ln (properties)	1.002***		1.081***		1.100***		1.005***		1.186***		1.099***	
	{0.000}		{0.000}		{0.000}		{0.000}		{0.000}		{0.000}	
ln (sludge produced)		0.940***		0.964***		1.075***		0.975***		1.099***		1.010***
		{0.000}		{0.000}		{0.000}		{0.000}		{0.000}		{0.000}
% intersiting work done by truck and tanker	0.020***	0.017***	0.016***	0.015**	0.017***	0.012**	0.020***	0.017***	0.017**	0.014**	0.013***	0.009**
	{0.003}	{0.010}	{0.005}	{0.023}	{0.010}	{0.036}	{0.003}	{0.006}	{0.025}	{0.041}	{0.002}	{0.020}
% of sludge disposed to farmland	-0.021**	-0.018**	-0.014**	-0.015*	-0.019**	-0.015**	-0.021**	-0.019**	-0.019**	-0.016*	-0.012**	-0.011*
	{0.021}	{0.026}	{0.029}	{0.055}	{0.030}	{0.048}	{0.025}	{0.026}	{0.041}	{0.056}	{0.020}	{0.058}
% tds treated by conventional or			-0.005**	-0.002							-0.008**	-0.005**
			{0.021}	{0.199}							{0.010}	{0.041}

Model ID	Ofwat OBR1	Ofwat OBR2	EI WW17	EI WW18	EI WW19	EI WW20	EI WW21	EI WW22	EI WW23	EI WW24	EI WW25	EI WW26
advanced anaerobic digestion												
% load treated in band 1-3 works					0.010** {0.012}	0.015*** {0.002}					0.009 {0.213}	0.020*** {0.000}
% of sludge produced and treated at a site of STW and STC co-location							{0.927}	-0.003 {0.334}			-0.006** {0.025}	-0.006** {0.011}
% of area with less than 250 people per km2									0.008** {0.034}	0.008** {0.034}	-0.007 {0.250}	-0.011** {0.017}
Constant	3.167** {0.017}	13.261*** {0.000}	2.112 {0.142}	13.216*** {0.000}	1.654* {0.066}	12.493*** {0.000}	3.157** {0.025}	13.422*** {0.000}	0.364 {0.748}	12.397*** {0.000}	2.534* {0.090}	13.669*** {0.000}
R2 adjusted	0.862	0.878	0.893	0.882	0.874	0.902	0.86	0.882	0.879	0.893	0.902	0.908
VIF (max)	2.536	2.47	2.71	2.695	2.832	2.827	2.543	2.476	3.152	3.04	20.326	19.101
Reset test	0.011	0.003	0.009	0.004	0.068	0.164	0.005	0	0.056	0.013	0.012	0.072
Estimation method	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
N (sample size)	60	60	60	60	60	60	60	60	60	60	60	60
YKY rank	8	8	9	8	10	10	8	8	10	10	9	8
YKY catch-up to frontier	30%	15%	21%	14%	33%	18%	30%	22%	34%	20%	22%	13%
YKY catch-up to UQ score	15%	11%	8%	9%	17%	10%	15%	15%	21%	17%	8%	4%

7.6 Efficiency score results

In this section we present our efficiency score results. Table 22 and Table 23 summarises the number of models in which Yorkshire is within the UQ and the number of models where YKY is the frontier.

In water, we see that Yorkshire is within the UQ score in 24 out of the 28 service level models and in 16 out of 17 network plus models. However, in resources none of the models are within the UQ score.

Similarly, in wastewater, 10 out of the 20 service level models and 21 out of the 23 network plus models are within the UQ score. As in water, in bioresources, none of the models are within the UQ score.

Table 22: Number of water models where YKY is the frontier and within the UQ score

Benchmark	Num. of models	Num. of models where YKY is within the UQ score	Num. of models where YKY is the frontier
Wholesale	28	24	12
Network plus	17	16	7
Resources	12	0	0

Source: Economic Insight

Table 23: Number of wastewater models where YKY is the frontier and within the UQ score

Benchmark	Num. of models	Num. of models where YKY is within the UQ	Num. of models where YKY is the frontier
Wholesale waste	20	10	0
Network plus	23	21	10
Bioresources	19	0	0

Source: Economic Insight

7.6.1 Efficiency score range

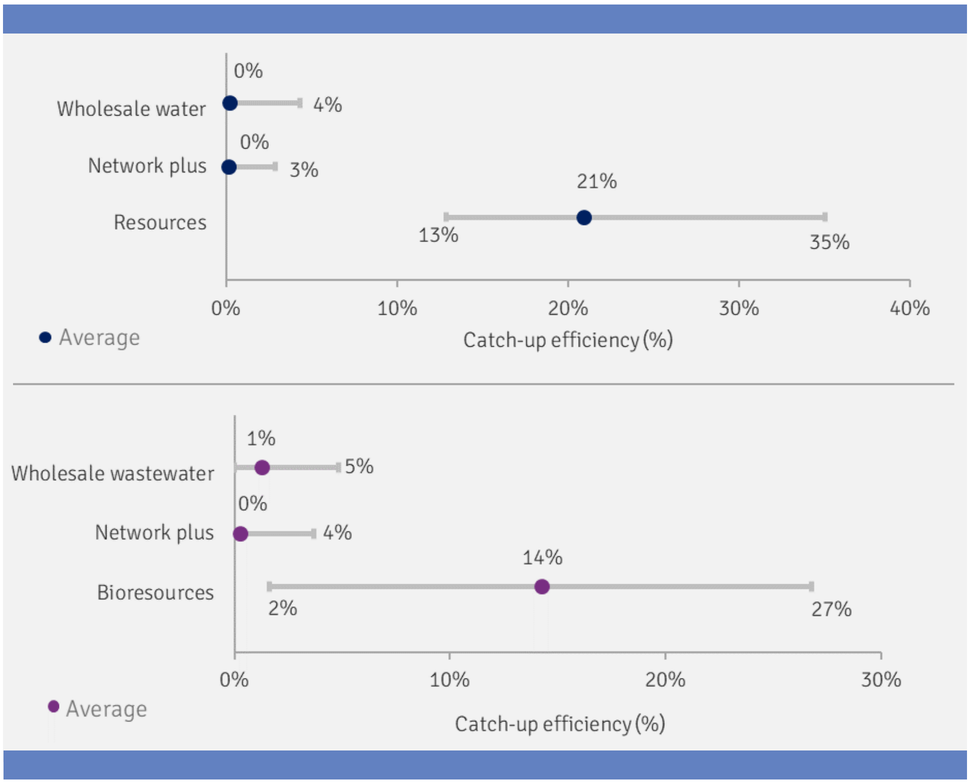
Figure 23 plots efficiency score ranges by service level and price control areas. These figures combine efficiency scores from Ofwat's, Oxera's and EI's models.

Across both water and wastewater, we see that the efficiency score ranges are similar for service level and network plus models. This is expected as network plus accounts for the largest proportion of the services. We also find that the efficiency scores are much higher and wider in the resources and bioresources models.

In water, we see that the range is widest in resources with a gap of **22%** between the maximum and minimum score. This indicates that the models are unstable as it appears to be highly sensitive to the choice of variables in the model. The range in wholesale water is between **0% to 4%** with an average of **0%** and the range in network plus is between **0% to 3%** with an average of **0%.**

In wastewater, the gap between the highest and the lowest score in bioresources is **25%.** The efficiency scores for wastewater services ranges from **0% to 5%** with an average of **1%** and in network plus the scores range from **0% to 4%** with an average of **0%.**

Figure 23: Efficiency score ranges for Yorkshire



Source: Economic Insight

7.7 Alternative efficiency scores for resources and bioresources models

The wide ranges observed in the resources and bioresources models indicate that the variation may not be entirely down to managerial inefficiency. To obtain a more reliable estimate, we have developed an innovative method wherein we infer an efficiency score for resources and bioresources from the gap between the service level and network plus models.

7.7.1 Method

We have applied the following method to calculate the resources and bioresources catch-up efficiency:

- First, we calculate the difference in the catch-up efficiency range between the service level and the weighted network plus models.
- Second, this difference is then apportioned by the relative size of the resources or the bioresources services.

The formula we apply here is essentially the rearranged formula of a weighted service level efficiency. For example, for water services the formula is:

$$Water\ services\ \% = \underbrace{\left(\frac{NP\ costs}{water\ services\ costs}\right)}_{ratio_{NP}} \times NP\% + \underbrace{\left(\frac{resources\ costs}{water\ services\ costs}\right)}_{ratio_{resources}} \times resources\ \%$$

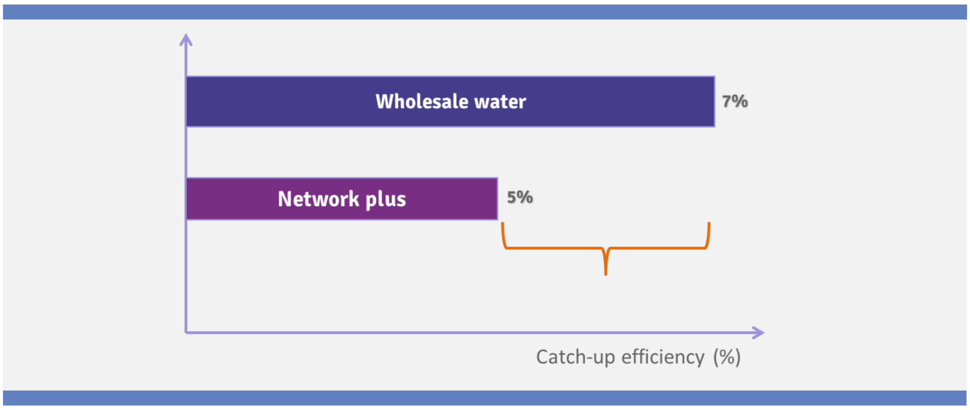
Rearranging this gives us tl ratio $_{NP}$ for resources: ratio $_{resources}$

$$Resources\ \% = \frac{water\ services\ \% - ratio_{NP} \times NP\%}{ratio_{resources}}$$

Below we present a worked example where we apply this calculation.

As illustrated in Figure 23 suppose the maximum range in the wholesale water models is 7% and in network plus it is 5%. Further, suppose that resources accounts for 20% and network plus accounts for 80% of total costs. Then applying the formula above gives us a catch-up efficiency of **15%** for resources.

Figure 24: Illustrative example for calculating resources efficiency



Source: Economic Insight

7.7.2 Alternative efficiency score results

Water resources

Across the industry, water resources accounts for 9% of total costs while network plus accounts for 91%. Our econometrics results show that the maximum range for water services is 4.3% and for network plus it is 2.9%. This gives us a catch-up efficiency of **19%** for water resources.

Table 24: Alternative efficiency score for water resources

Formula	Calculation	Results
$Water\ resources\ \% = \frac{water\ services\ \% - ratio_{NP} \times NP\ \%}{ratio_{water\ resources}}$	$= \frac{4.3\% - (0.91 \times 2.9\%)}{0.09}$	**19%**

Source: Economic Insight

<u>Wastewater resources</u>

The bioresources area accounts for 18% of total costs while network plus accounts for 82%. The maximum range we obtain for wastewater services is 4.8% and for network plus it is 3.7%. This gives us a catch-up efficiency of 10% for bioresources.

Table 25: Alternative efficiency score for bioresources

Formula	Calculation	Results
$Bioresources\ \% = \frac{wastewater\ services\ \% - ratio_{NP}\ \times NP\ \%}{ratio\ _{bioresources}}$	$= \frac{4.8\% - (0.82 \times 3.7\%)}{0.18}$	**10%**

Source: Economic Insight

8. Annex C: Cross sector benchmarking - literature review

In this section we set out in detail the findings from our cross-sector literature review. We have examined existing studies that estimate the average annual RUOE reductions for comparable network industries. We have found that, after excluding outliers, the average RUOE reductions per annum of the electricity, gas, rail and telecoms sectors lies between 4.3% and 5.1% over the period from 1980/81-2012/13.

In the final methodology for PR19, Ofwat stated that they aim to set an efficiency challenge for water companies based, in part, on a comparative assessment of other sectors in the economy. In keeping with this, we have looked to undertake our own analysis of the efficiency savings achieved by comparable regulated sectors. Our approach included conducting both a review of the existing literature, and to supplement these findings with our own quantitative analysis of changes in RUOE across sectors over the period 2011-12 to 2016-17.

This section details our findings from the literature review, much of which relates to an earlier time period than our own analysis, and therefore helpfully supplements and informs our own quantitative assessment.

8.1 Summary of literature

This section summarises the 8 papers used in our literature review, paying particular attention to the methodology and corresponding results of RUOE analysis.

Bishop and Thompson (1992) '*Regulatory reform and productivity growth in the UK's public utilities*', Applied Economics.

Paper overview

The paper examines the extent to which the regulatory reforms that took place in the 1980s, including privatisation, succeeded in increasing the efficiency of firms. To do so, Bishop and Thompson analyse the change in productivity performance of the nine largest nationalised industries over the 1970s and 1980s, before distinguishing how much of this change in productivity can be attributed to improvements in efficiency.

Methodology of efficiency assessment

Bishop and Thompson calculated productivity growth rates for British Airways, BAA, British Coal, British Gas, British Rail, British Steel, British Telecom, Electricity Supply and the Post Office over the 20 years from 1970 to 1990.

Both labour productivity and total factor productivity was measured using a weighted index of the growth rates of inputs and outputs.

- Indices for the **output** of each enterprise was estimated from data recording the physical volume of the output of different goods or services supplied by each enterprise, weighted by the share of total revenue in each year. For **BAA**, the scale variables used were **air transport movements** and **passenger arrivals/departures**.
- Where data availability permitted, weighted indices for **inputs** were disaggregated into 4 components: labour, capital energy and other.

No explicit adjustment was made for changes in product quality over the period.

Results

The results showed that productivity growth rates varied significantly for enterprises included in the study, and that generally, productivity growth was more rapid over the 1980's compared with the 1970's.

For **BAA**, annual TFP growth averaged **4.8%** over 1970-80, and **0.3%** over 1980-90.

Conclusion

Bishop and Thompson note that changes in productivity may result from a combination of scale effects, technical progress, changes in technical efficiency and the efficiency with which prices are set. By analysing the changes in labour productivity and output alongside TFP growth, the authors concluded that scale effects and factor substitution explain a portion of the TFP growth, yet a large part of the change can be attributed to increases in efficiency.

As such, Bishop and Thompson conclude that the productivity growth in the nine major public enterprises included in the study generally increased faster after regulatory reform, and much of this increase can be attributed to improved efficiency.

Europe Economics (2000), '*Analysis of responses to "Review of Railtrack Efficiency": A report for the Office of the Rail Regulator*'

Paper overview

In 1999, Europe Economics was commissioned to provide an analysis of the potential for Railtrack to make efficiency gains. Europe Economics' top down approach included identifying comparable industries and evaluating evidence of their efficiency improvements, before assessing the implications of this regarding the scope for Railtrack to reduce its expenditures. The follow up paper in 2000 summarises the findings of their 1999 paper, while addressing responses. After addressing points raised by both Railtrack and Oxera, Europe Economics concluded that its recommendations for Railtrack's efficiency target would remain at 3-5% RUOE savings per annum.

Methodology of efficiency assessment (1999 paper)

Industries were selected as suitable comparators if the management of infrastructure is their primary activity; they are subject to little direct competition; and they are privatised and subject to economic regulation. Comparable industries were therefore decided to be: **water, sewerage, electricity transmission, electricity distribution and gas transportation**.

For these industries, unit operating costs reductions (excluding depreciation) per annum were calculated over a comparable phase of their post-privatisation history. (The 2000 report did not include information regarding scale variables used).

Results (1999 paper)

Sector	Time period	Compound annual RUOC reductions
Water	1994-1998 (4 years)	3.7%
Sewerage	1994-1998 (4 years)	4.1%
Electricity transmission	1992-1998 (6 years)	6.5%
Electricity distribution	1992-1998 (6 years)	6.8%
Gas transportation	1988-1998 (10 years)	9.1%

Europe Economics note that in using unit operating cost reductions to inform the potential to reduce aggregate operating costs, economies of scale must be accounted for. Gas transportation was therefore removed at this stage, due to likely distortions resulting from significant growth in throughput. Results therefore show that comparable firms were able to reduce operating costs by **3% to 7%** per annum. They found no evidence of the rate of cost reduction falling with the length of the period since privatisation.

Further, in moving from conclusions regarding potential aggregate operating cost reductions to the implications for reducing overall expenditures, account needs to be taken of capital substitution. Their analysis shows that the comparator industries have reduced RUOE (excluding depreciation) by 5.6% per annum on average, while they have reduced RUOC (including depreciation) by 4.1% per annum on average, suggesting that an appropriate **capital substitution adjustment may be of the broad order of 1-2% pa**.

Conclusions (1999 paper)

Europe Economics concluded that after accounting for economies of scale and capital substitution, it seemed reasonable to assume that Railtrack could reduce expenditures by the order of **3-5% per annum**.

Notable criticisms/considerations (2000 paper)

Europe Economics addressed a number of responses to their original paper, namely those of Railtrack and Oxera. The response that Europe Economics considered of the most merit, was the criticism that Railtrack faces far greater labour costs than its comparators. Europe Economics responded that any adjustment would depend on the view as to the proportion of additional labour costs which result from factors outside of management control, which would be difficult to quantify. As a result, Europe Economics' assessment remained that Railtrack has the scope to reduce expenditures by **3-5%** per annum.

The annex of the document contains changes in RUOE since privatisation for 25 companies, which have been referenced in our own analysis.

CEPA (2003), '*Productivity improvements in distribution network operators', report for Ofgem'*

Paper summary

In 2003, Ofgem commissioned CEPA to assess the potential for electricity distribution networks to make efficiency gains over the distribution price control DPCR5.

In doing so, CEPA study historic trend productivity of the UK economy as a whole, the distribution network operators (DNOs) themselves, other UK privatised utilities, international distribution utilities, as well as sectoral and composite sectoral UK estimates. This analysis was supplemented by an analyst and company survey, providing further insights into the scope for efficiency savings.

CEPA found that the DNOs have exhibited significant productivity growth since privatisation, yet argued that such large cost reductions would be unlikely to continue to be available in future years. CEPA forecast TFP growth for DNOs to lie between 1.2-3.4%, while PFP growth to lie between 2-5% over DPCR5.

Methodology of cross sector efficiency assessment

In undertaking their analysis of the efficiency gains of DNOs and other UK privatised utilities (electricity transmission, water and sewerage, fixed line telecoms, and rail), CEPA measured both TFP and PFP using Tornqvist indices; ratios of weighted combinations of outputs, to weighted combinations of inputs. CEPA note that the PFP opex index is the inverse of RUOE, and as such both of these measure the same effect.

Where possible, CEPA adjusted for economies of scale and quality. For DNOs, CEPA use a scale elasticity of 0.85. CEPA also added a quality variable to the indices for water and electricity sectors.

Results

CEPA published a number of results. Below, we have aggregated the PFP opex CAGR, after the aforementioned adjustments, for the privatised utilities sectors included in the study.

Sector	Time period	Scale variable	PFP opex CAGR
Telecoms (British Telecom)	1997/8-2001/2	Number of exchange lines, call minutes	9.30%
Electricity transmission (National Grid)	1991/2-2001/2	Electricity requirements, TWh	2.50%
Electricity distribution (DNOs)	1991/2-2001/2	Customer numbers, units distributed (GWh)	7.70%
Rail (Railtrack)	1995/6-2001/2	Passenger train km, freight train km	5.50%
Water and sewerage	1994/5-2001/2	Customer numbers, water delivered or sewerage collected Ml/day	8.30%

CEPA highlighted a number of factors that may explain the high PFP growth seen for the DNOs. These include:

- Relatively recent privatisation.
- Revised price controls resulting in substantial improvement in 1999/00 and 2000/01.

Conclusions

Given the PFP analysis, as well as the other evidence included in the study, CEPA expected TFP to lie in the range of **1.2% to 3.4%** with a central case expectation of **2.4%.** PFP was expected to improve between **2% to 5%** over the same time frame, with a central estimate of **3.5%.**

Oxera Consulting Ltd and L.E.K Consulting (International) Ltd (2005), report for the Office of Rail Regulation, '*Assessing Network Rail's scope for efficiency gains over CP4 and beyond: a preliminary study*'

Paper summary

Oxera and LEK Consulting were commissioned by the ORR to make an assessment of the scope for efficiency gains for Network Rail over the CP4 and CP5 price control periods. To do this, Oxera and LEK Consulting examined Network Rail's historic performance, the experience of efficiency gains of other regulated industries, the performance of competitive industries, and the performance of privatised railways overseas.

After analysing the evidence gathered throughout the study, Oxera and LEK Consulting conclude that the plausible scope for unit cost reduction over CP4 was approximately 2% - 8% per annum, while over CP5 it reduced slightly to 1.5% - 5%.

Methodology of efficiency assessment (incl. scale variable)

Oxera and LEK Consulting examine RUOE trends across sectors to estimate cost reduction targets, and use TFP evidence to identify plausible frontier shift estimates. Suitable cross sector comparators were selected based upon providing network infrastructure services, and also being subject to economic regulation.

Comparators were decided to be water and sewerage, electricity transmission and distribution, and telecoms. Gas was excluded owing to the sector undergoing significant restructuring activity since 1996, which led to data volatility.

In calculating RUOE, adjustments were made for volume growth. Additionally, yearly averages were displayed as the average annual growth rate rather than the compound annual growth rate, with the aim of minimising the sensitivity to the start and end points of the available data.

Efficiency estimates

Results of Oxera and LEK Consulting's RUOE analysis is presented in the table below.

Sector	Time period	Scale variable	RUOE reduction (average % p.a.)
Water industry (control for quality enhancement)	1992/93-2003/04	Unspecified	2.5%

Sewerage industry (control for quality enhancement)	1992/93-2003/04	Unspecified	2.6%
Electricity distribution	1990/91-2000/01	Unspecified	3.8%
National Grid Company	1990/91-2001/02	Units transmitted	5.7%
BT	1996/97-2003/04	Call volumes	10.3%
BT	1996/97-2003/04	Exchange lines	3.8%

The significant variance in the above results was hypothesised to be partially due to differences in the initial level of inefficiency, which may have led to faster rates of catch up, as well as differences in the technological advances occurring between industries and other industry-specific events. Oxera and LEK Consulting remove BT (measured using call volumes) as an outlier.

The results were then aggregated according to the corresponding control period, as well as the number of years since privatisation, as follows:

	Control period 2	Control period 3	6-10 years since privatisation	11-15 years since privatisation
Range	3% - 12.8%	-1.5%- 13.2%	3.7% - 4.5%	-1.5% - 9.6%
Average	6.5%	5.2%	4.3%	2.9%

Oxera and LEK Consulting note that the above results are consistent with improvement decreasing over time.

Conclusions

In drawing conclusions from the aforementioned data, Oxera and LEK Consulting note that there are certain difficulties, namely:

- The catch-up element of efficiency improvements is dependent upon the relative inefficiency of the company/industry at the start of the period being measured.
- The comparator industries have not experienced a cost shock of the magnitude of the Hatfield derailment, which may hinder comparability.

After considering these difficulties alongside all evidence included in the study[9], Oxera and LEK Consulting conclude that a plausible range for unit cost efficiency gains lies between 2% - 8% per annum for CP4, and between 1.5% - 5% over CP5.

Oxera (2008), report for the Office of Rail Regulation, '*Network Rail's scope for efficiency gains in CP4*'

Paper summary

In this report, Oxera look to update the previous analysis by Oxera and LEK Consulting conducted in 2005. Oxera look to provide an assessment of the efficiency gains achievable by Network Rail in OM&R expenditure, to inform the 2008 periodic review.

[9] *Evidence includes a review of Europe Economics (2003) RUOE estimates, which we have included in our own aggregation of RUOE figures in the following section.*

The study focused on indirect measures of efficiency, by examining both economy wide productivity trends as well as rates achieved by other comparable, regulate industries.

Methodology of efficiency assessment

In choosing relevant comparators for cross-sector efficiency analysis, Oxera focused on privatised and price regulated network industries, which are viewed as sharing the most characteristics with Network Rail.

As part of their analysis, Oxera calculated the OPEX RUOE reductions per annum of water and sewerage, electricity transmission and distribution, gas distribution and telecommunications companies.

Cash maintenance was included in the OPEX measure for all industries except gas distribution, and figures were adjusted for economies of scale. The period between 1999/00 – 2000/01 was omitted for electricity distribution companies, owing to abnormally large RUOE reductions. Additionally, due to changes in the structure of gas distribution, Oxera decided to examine the RUOE trend of Ofgem's projections of unit costs over the upcoming price control period. For all other sectors, the period analysed was dependent upon data availability.

Efficiency estimates

Oxera's cross-sector efficiency estimates are included in the table below.

Sector	Time period	Scale variable	OPEX RUOE reduction (average % p.a.)
E&W water	1992/93-2006/07	Water delivered	1.8%
E&W sewerage	1992/93 – 2006/07	Population connected	1.7%
Scottish Water (water)	2002/03 – 2005/06	Water delivered	8.8%
Scottish Water (sewerage)	2002/03 – 2005/06	Population connected	14.3%
Electricity distribution	1990/91 – 2006/07	Total units distributed	4.0%
Gas distribution	2008/09 – 2012/13	Annual demand forecast	2.3%
National Grid Company	1990/91 – 2006/07	Units transmitted	4.9%
BT	1996/97 – 2006/07	Call minutes	6.2%
BT	1996/97 – 2006/07	Exchange lines	4.8%

Oxera note the comparatively low scores for the England and Wales water and sewerage sectors, and hypothesise that in part this may be a result of relatively slow technological progress in this industry compared to others.

Scottish Water on the other hand shows significant reductions in RUOE, however, Oxera exclude these results from further analysis, owing to the sector only being subject to regulation since 2002/03, making it a less reliable comparator. Gas distribution was also removed from further analysis.

After excluding for outliers, Oxera reach an estimate of the central OPEX RUOE reduction across sectors, of 4% to 6.2% per annum.

Oxera also considered the data as grouped by control period and the number of years since privatisation. After taking into account the reset hypothesis, Oxera considered Network Rail to be in the second price control period, and in the 6-10 year period since privatisation.

Oxera calculated the range of opex RUOE reductions for control period 2 as 4.5% and 12.8% per annum, with an average of 6.8%. For the 6-10 year period since privatisation, the range was calculated as 4.5% to 6.3% per annum across sectors, with an average of 5.2%.

Conclusions

After considering both the RUOE analysis, and the other evidence included in the study, Oxera conclude that an average of 4% - 6.5% efficiency gains per year is a suitable target for Network Rail.

Reckon (2011), report for the Office of Rail Regulation, '*Productivity and unit cost change in UK regulated network industries and other UK sectors: initial analysis for Network Rail's periodic review*'

Paper summary

The ORR commissioned Reckon to update the efficiency analysis of Network Rail conducted by Oxera (2008). In doing so, Reckon estimated historical unit operating cost expenditure for comparable regulated network industries in the UK, productivity growth estimates across sectors in the UK, and reviewed prior use of this information in forming efficiency targets.

Methodology of efficiency assessment (incl. scale variable)

Reckon closely followed the methodology of Oxera (2008) when conducting their RUOE analysis. To update their figures, Reckon calculated the remaining 4-5 years through 2009/10 that were not included in Oxera's analysis, before taking the annual average RUOE. This was combined with Oxera's estimates and weighted in order to estimate a new average per annum, across the combined period.

Reckon decided to exclude BT from their analysis, on the grounds that call minutes and exchange lines are no longer reasonable to be taken as output measures.

RUOE efficiency estimates

Sector	Time period	Scale variable	RUOE reduction (weighted average % p.a.)
Electricity distribution	1990/91-2009/10	Electricity distributed	2.7%
National Grid Electricity Transmission	1990/91-2009/10	Electricity transmitted	3.6%
England and Wales water	1992/93-2009/10	Water delivered	1.4%
England and Wales sewerage	1992/93-2009/10	Properties billed	1.6%

Scottish water	2002/03-2009/10	Water delivered	1.9%
Scottish sewerage	2002/03-2009/10	Population connected	5.4%

Reckon find that the large reductions in RUOE seen in Oxera have not been repeated over the last 4to 5 years.

The reason for this was hypothesised to be due to some of Oxera's estimates being affected by a period of high productivity gains following privatisation and/or by a period in which network firms shifted away from operating expenditure and instead increased capital expenditure in response to the incentives brought about by price control regulation.

Conclusions

After considering their RUOE analysis alongside a range of other evidence included in the study, Reckon conclude that the plausible range of efficiency reductions per annum put forward by Oxera (2008), which was taken by the ORR in setting targets for the periodic price review from 2009/10 to 2014-15, was too high.

CEPA (2012), report for the Office of Rail Regulation, '*Scope for improvement in the efficiency of Network Rail's expenditure on support and operations: supplementary analysis of productivity and unit cost change*

Paper summary

ORR commissioned CEPA to estimate Network Rail's scope for achieving efficiency gains in operations and support costs over Control Period 5 (CP5), looking at both historical performances of other UK network industries and different sectors' productivity performance.

CEPA look at top down estimates of productivity performance; RUOE, TFP and LEMS (labour, energy, materials and services cost measure), using comparators from other industries as benchmarks.

Methodology of RUOE efficiency assessment (incl. scale variable)

In undertaking a RUOE analysis, CEPA gather data for a total of 46 companies across the water and sewerage industries, electricity transmission and distribution, as well as gas transmission and distribution. The decision was taken to omit telecoms, as, similarly to Reckon, the output measures (call minutes and exchange lines) were considered as no longer appropriate given the range of services now offered.

In calculating RUOE savings, CEPA adjust for economies of scale using cost elasticities, the estimates of which were informed by a literature review.

RUOE efficiency estimates

Sector	Time period	RUOE CAGR (controllable opex)	Scale variable	Cost elasticity
Electricity distribution	1992/3-2009/10	3.0%	Customer numbers	0.72
Electricity transmission	1992/3-2010/11	5.6%	Electricity demand (MWh)	0.72

Gas distribution	2006/07-2009/10	2.1%	Customer numbers	0.90
Gas transmission	2002/03-2009/10	2.9%	Annual demand (throughput)	0.90
Water (England and wales)	1992/3-2010/11	1.1%	Water delivered / properties billed	0.96
Sewerage (England and Wales)	1992/3-2010/11	0.3%	Population connected / properties billed	0.96

CEPA averaged the above annual changes in RUOE by control period across all comparator industries, as well as by the number of years since privatisation. They found that, across comparator industries, RUOE efficiency averaged 3.3% per annum in the third price control period, and 3.7% over the 11-15 years since privatisation.

After taking the reset hypothesis into account (the assumption that the sharp rise in costs following the Hatfield derailment and Network Rail's administration reset Network rail's opex to pre-privatisation levels), and excluding outliers (England and Wales sewerage), the range of average annual cost reduction is 2.1% - 6.5% for price control 3 and 2.1% - 6.7% for 11-15 years since privatisation.

Conclusions

Taking all of the evidence included in the study into account, CEPA concluded that annual RUOE efficiency savings of 4.4% might represent an appropriate target for Network Rail over CP5.

CEPA (2013), report for the CAA, '*Scope for efficiency gains at Heathrow, Gatwick and Stansted airports*'

Paper summary

The Civil Aviation Authority commissioned CEPA to assess the potential for opex efficiency improvements at the UK's designated airports (Heathrow, Gatwick and Stansted).

In assessing the scope for improved efficiency, CEPA undertook both a qualitative and quantitative analysis. In their qualitative analysis, CEPA included a literature review of efficiency benchmarking, cost elasticities, recent regulatory precedent and relevant academic reports. In their quantitative analysis, CEPA compared a range of productivity metrics (including PFP measures such as labour productivity, RUOE, LEMS and adjusted TFP, as well as a number of TFP measures) for the past performance of firms within the industry, as well as for other comparative industries.

Methodology of efficiency assessment (incl. scale variable)

In their RUOE analysis, CEPA include the electricity transmission and distribution, gas transmission and distribution, as well as water and sewerage sectors as comparators, alongside international airports. These were chosen as comparators on the grounds that they are all regulated industries that have been incentivised to continually improve performance. Telecoms was excluded as the output measures (call minutes and exchange lines), were no longer considered appropriate.

In estimating RUOE savings, CEPA made no adjustment for quality, and note that although changes in quality can influence the productivity metrics, they view that all regulated comparator sectors in the analysis have shown improvements in quality of their services delivered, and thereby the effect would be minimal. CEPA do make an adjustment for scale effects, by applying an elasticity to productivity metric calculations.

Efficiency estimates

Sector	Time period	Average RUOE efficiency (%p.a.)	Scale variable	Cost elasticity
Airports (UK designated)	1997/98-2011/12	-1.2%	Number of passengers, WLUs	0.50
Airports (UK non designated)	2000/01-2011/12	0.3%	Number of passengers, WLUs	0.50
Airports (non-UK)	2000/01-2011/12	0.0%	Number of passengers	0.50
Rail	2002/03-2009/10	3.1%	Passenger train km	0.20
Electricity distribution	1992/3-2009/10	2.5%	Customer numbers	0.72
Electricity transmission	1992/3-2010/11	4.9%	Electricity demand (MWh)	0.72
Gas distribution	2006/07-2009/10	2.1%	Customer numbers	0.90
Gas transmission	2002/03-2009/10	2.9%	Annual demand (throughput)	0.90
Water (England and wales)	1992/3-2010/11	1.3%	Water delivered / properties billed	0.96
Water (Scotland)	2002/03-2010/11	2.1%	Water delivered / properties billed	0.96
Sewerage (England and Wales)	1992/3-2010/11	0.2%	Population connected / properties billed	0.96
Sewerage (Scotland)	2002/03-2009/10	5.3%	Population connected / properties billed	0.96

In order to interpret these results, CEPA outline several factors pertaining to the airport sector that ought to be considered. These factors include:

- Falling passenger numbers over the period 2007-10, as a result of declining economic conditions, will likely affect RUOE efficiency scores.
- There are significant variations in airport utilisation between the UK's designated airports which may affect the RUOE efficiency scores between them.
- The passenger mix of different airports will impact costs; airports with a higher proportion of full service, as opposed to budget airlines, will require higher quality airport amenities.
- Legislation imposing higher security costs is outside of management control, however will affect RUOE efficiency.

After removing outliers (England and Wales sewerage) CEPA also aggregate the data by year since privatisation. They find that the average RUOE efficiency per annum across sectors more than 10 years since privatisation is 0.1% (range -3.6% - 2.6%), while more than 15 years since privatisation this rises to 0.2% (range -2% - 2.8%). In performing these calculations, CEPA assume the reset hypothesis for the

rail sector (the Hatfield derailment and period of administration reset Network rail to pre-privatisation efficiency).
Conclusions

CEPA conclude that although it is unclear why airports perform relatively poorly in comparison to other sectors, this may imply that there remains scope for catch up efficiency that hasn't been delivered in the period of privatisation. Therefore, the results suggest there is scope for efficiency savings at all three designated airports.

8.2 Aggregation of existing efficiency estimates by sector

In this section, we combine the results obtained throughout the studies included in our literature review by sector, in order to identify the range of RUOE efficiency savings put forward from previous studies, and also to identify any outliers or trends.

8.2.1 Electricity transmission

Figure 25: RUOE efficiency savings achieved by electricity transmission companies, literature review

Time	RUOE efficiency p.a.	Cost driver	Adjustments	Source
1990/91-2001/02	5.7%	Units transmitted	Economies of scale	LEK Oxera (2005)
1990/91-2006/07	4.9%	Units transmitted	Economies of scale	Oxera (2008)
1990/91-2009/10	3.6%	Electricity transmitted	Adjusted for weather	Reckon (2011)
1991-1998	6.8%	Unspecified	Unspecified	Europe Economics (2000)
1991-2001	5.3%	Unspecified	Economies of scale	Europe Economics (2003)
1991/2-2001/2	2.5% (PFP)	Electricity requirements (TWh)	Economies of scale, quality	CEPA (2003)
1992/93-2010/11	5.6%	Electricity demand (MWh)	Economies of scale	CEPA (2012)
1992/93-2010/11	4.9%	Electricity demand (MWh)	Economies of scale	CEPA (2013)
Range	**2.5% - 6.8%**			

The results obtained from the literature review show that RUOE efficiency achieved by electricity transmission companies ranged between 2.5% to 6.8% per annum, over the period from 1990/91 to 2010/11. Similar cost drivers were used throughout the literature, and the majority of studies made adjustments for economies of scale. Reckon (2011) also made adjustments for weather, as adverse weather events are both outside of management control, and have a bearing on cost, and therefore are likely to distort the RUOE efficiency score.

The midpoint RUOE efficiency per annum for electricity transmission companies is **4.7%.**

8.2.2 Electricity distribution

Figure 26: RUOE efficiency savings achieved by electricity distribution companies, literature review

Time	RUOE average efficiency p.a.	Cost driver	Adjustments	Source
1990-1998	6.5%	Unspecified	Unspecified	Europe Economics (2000)
1990/91-2000/01	3.8%	Unspecified	Economies of scale	LEK Oxera (2005)
1990/91-2006/07	4.0%	Total units distributed	Economies of scale	Oxera (2008)
1990/91-2009/10	2.7%	Units distributed	Economies of scale	Reckon (2011)
1991/92-2001/02	7.7% (PFP)	Customer numbers, units distributed	Economies of scale, quality	CEPA (2003)
1992/93-2009/10	2.5%	Customer numbers	Economies of scale	CEPA (2013)
1992/3-2009/10	3.0%	Customer numbers	Economies of scale	CEPA (2012)
Range	**2.5% - 7.7%**			

Results from the literature review show that average RUOE efficiency achieved by DNOs over the period between 1990 to 2009/10 ranges between 2.5% and 7.7% per annum.[10] The values vary quite widely, although the variation does not appear to correlate with the choice of cost driver. However, it can be seen that studies covering more recent time periods (up to 2009/10), tend to have lower average scores (ranging between 2.5% to 3.0%). This is consistent with the hypothesis that the scope for efficiency savings is higher following privatisation, and falls with time as these initial savings are realised.

The midpoint RUOE efficiency per annum for electricity distribution companies is **5.1%.**

[10] Note that PFP and RUOE efficiency measures can be interpreted in the same way.

8.2.3 Gas networks

Figure 27: RUOE efficiency savings achieved by gas networks, literature review

Time	RUOE average efficiency p.a.	Cost driver	Adjustments	Source
1986/87-1995/96	7.5%	Gas throughput (TWh)	Unspecified	Europe Economics (2000)
2002/03 – 2009/10	2.9%	Annual demand (throughput)	Economies of scale	CEPA (2012)
2002/03-2009/10	2.5%	Annual demand (throughput)	Economies of scale	CEPA (2013)
2002/03-2009/10	2.9%	Annual demand (throughput)	Economies of scale	CEPA (2012)
2006/07-2009/10	2.1%	Customer numbers	Economies of scale	CEPA (2012)
2006/07-2009/10	2.1%	Customer numbers	Economies of scale	CEPA (2013)
2008/09-2012/13	2.3%	Annual demand forecast	Economies of scale	Oxera (2008)
Range	**2.1% -7.5%**			

The results obtained from the literature review show that RUOE efficiency achieved by gas network operators ranged between 2.1% to 7.5% per annum, over the period from 1986/87 to 2012/13. By reducing the time period from 2002/03 to 2012/13, the range drops to 2.1% to 2.9%. Again, this is consistent with the hypothesis that the scope for efficiency savings falls over the period since privatisation.

The midpoint of results obtained from the literature review is **5.7%** RUOE efficiency savings on average per annum.

8.2.4 Telecoms (BT)

Figure 28: RUOE efficiency savings achieved by BT, literature review

Time	RUOE average efficiency p.a.	Cost driver	Adjustments	Source
1983/84-1992/93	4.8%	Call minutes	Unspecified	Europe Economics (2000)
1988-2002	-1.1%	Exchange lines	Unspecified	Europe Economics (2003)
1993-2002	1.9%	Call minutes	Unspecified	Europe Economics (2003)
1996/97-2003/04	3.8%	Call volumes	Economies of scale	LEK Oxera (2005)
1996/97-2003/04	10.3%	Exchange lines	Economies of scale	LEK Oxera (2005)
1996/97-2006/07	6.2%	Call minutes	Economies of scale	Oxera (2008)
1996/97-2006/07	4.8%	Exchange lines	Economies of scale	Oxera (2008)
1997/98-2001/02	9.3% (PFP)	Number of exchange lines, call minutes	Economies of scale	CEPA (2003)
Range	**-1.1% - 10.3%**			

The literature review provides a range of average RUOE efficiency scores for BT of between -1.1% to 10.3% per annum. Multiple studies decided to remove telecoms from consideration owing to the opinion that the cost drivers are unrepresentative of BT's rapidly changing scope of operations. This choice of cost driver may in part explain the wide variation in results.

The midpoint of the results is a RUOE efficiency saving of **4.6%** per annum.

8.2.5 Airports

Figure 29: RUOE efficiency savings achieved by airports, literature review

Time	RUOE average efficiency p.a.	Cost driver	Adjustments	Source
1980-1990	0.3% (TFP)	Air transport movements, passenger arrivals/departures	Unspecified	Bishop and Thompson
1987-1998	1.6%	Unspecified	Unspecified	Europe Economics (2000)
1997/98-2011-12	-1.2% (UK designated)	Number of passengers, WLUs	Economies of scale	CEPA (2013)
2000/01-2011-12	0.3% (UK other)	Number of passengers, WLUs	Economies of scale	CEPA (2013)
Range	**-1.2% - 1.6%**			

The efficiency savings achieved by airports range between -1.2% to 1.6% according to existing literature, over the period from 1980 to 2011/12. This range falls well below that achieved by other sectors reviewed. CEPA (2013) hypothesised that this was, in part, a result of falling passenger numbers owing to economic downturn in the mid to late 2000's, as well as high costs incurred through the imposition of more stringent safety regulations.

The TFP figure for the 10 years through 1990 was also included as a further point of comparison, as fewer studies include airports in their analysis.

The midpoint of the results is a RUOE efficiency saving of on average **0.2%** per annum.

8.2.6 Rail

Figure 30: RUOE efficiency savings achieved by rail operators, literature review

Time	RUOE average efficiency p.a.	Cost driver	Adjustments	Source
1995/96-2001/02	5.5% (PFP)	Passenger train km, freight train km	Economies of scale	CEPA (2003)
1995-2002	4.8%	Passenger numbers	Unspecified	Europe Economics (2003)
1995-2002	0.0%	Route length	Unspecified	Europe Economics (2003)
2002/03-2009/10	3.1%	Passenger train km	Economies of scale	CEPA (2013)
Range	**0.0% - 5.5%**			

The average RUOE efficiency savings achieved by rail operators ranged between 0.0% to 5.5% per annum, according to existing literature. The choice of scale variable appears to have a significant effect on the results, with route length resulting in no efficiency improvements being achieved on average. We have decided to remove the observation that calculates RUOE efficiency by using route length, on the basis that using passenger numbers provides a more holistic view of the requirement of operators to increase services due to rising demand.

Following the removal of this outlier, the average RUOE efficiency per annum lies between **3.1% to 5.5%** per annum, with a midpoint of **4.3%**.

8.3 Cross-sector summary

The table below summarises the range and midpoint of results obtained for each sector analysed through the literature review.

Figure 31: Summary of RUOE savings obtained from literature review, by sector

	Time period	Range (average efficiency reduction p.a)	Midpoint
Electricity transmission	1990/91-2010/11	2.5% - 6.8%	4.7%
Electricity distribution	1990-2009/10	2.5% - 7.7%	5.1%
Gas networks	1986/87-2012/13	2.1% -7.5%	4.6%
Telecoms	1983-2007	-1.1% - 10.3%	4.6%
Airports	1980-2012	-1.2% - 1.6%	0.2%
Rail	1995/96 – 2010/11	3.1% - 5.5%	4.3%
Range		**-1.2% - 10.3%**	**0.2% - 5.1%**

The central estimate varies between 0.2% and 5.1% average RUOE efficiency savings per annum across all sectors. The airport sector achieves far lower efficiency savings than all other sectors included, and removing this outlier results in a much narrower range of results, of between 4.3% and 5.1% per annum.

8.4 Sources

Below we list the sources used in conducting our literature review.

Bishop and Thompson (1992), *Regulatory reform and productivity growth in the UK's public utilities*, Applied Economics.

Europe Economics (2000), *Analysis of responses to 'Review of Railtrack efficiency'*, a report for ORR.

CEPA (2003), *Productivity improvements in distribution network operators*, report for Ofgem.

L.E.K Consulting and Oxera (2005), *Assessing Network Rail's scope for efficiency gains over CP4 and beyond*, report for ORR.

Oxera (2008), *Network Rail's scope for efficiency gains over CP4 and beyond*, report for ORR.

Reckon (2011), *Productivity and unit cost change in UK regulated network industries and other UK sectors: initial analysis for Network Rail's periodic review*, report for ORR.

CEPA (2012), *Scope for improvement in the efficiency of network rail's expenditure on support and operations: supplementary analysis of productivity and unit cost change*, report for ORR.

CEPA (2013), *Scope for efficiency gains at Heathrow, Gatwick and Stansted airports*, report for CAA.

9. Annex D: Cross sector benchmarking – RUOE analysis

In this section we detail the findings from our cross-sector RUOE efficiency analysis. We have examined data for the water and wastewater, electricity distribution and transmission, rail, telecommunications and airports sectors, over the period 2011/12 to 2016/17. We have found that, excluding outliers, these sectors have been able to achieve average RUOE efficiency savings of between 1.4% to 5.1% per annum.

In this section we detail the findings of our own analyses of changes in RUOE over the period 2011-12 to 2016-17, across regulated infrastructure sectors considered comparable to the water and wastewater sectors.

9.1 Data

Across the seven sectors included in our study, we gathered data for 47 firms, amassing a total of 278 observations.

In sourcing data for the water and wastewater sectors, we used the regulatory accounts published by Ofwat. For all other sectors, we collected data for operating costs and scale variables from their company accounts.

9.2 Methodology

For each firm included in our analysis, we calculated their level of operating expenditure per year over 2011-12 to 2016-17. Operating expenditure was measured as operating costs less amortization and depreciation, before adjusting for inflation using the RPI index. Following this, we calculated the real unit operating expenditure per annum using an appropriate scale variable.

The year on year percentage change was calculated within each company, before the average was taken across the period for all companies per sector.

In order to establish an appropriate range, the average RUOE annual percentage change for each year was taken across companies per sector. The year in which firms averaged the lowest annual RUOE reduction was taken as the minimum of the range, while the year averaging the highest efficiency improvement across the sector was taken as the maximum.

9.3 Results

Below we set out the average RUOE reduction and range of RUOE efficiency values per sector, over 2011/12 to 2016/17.

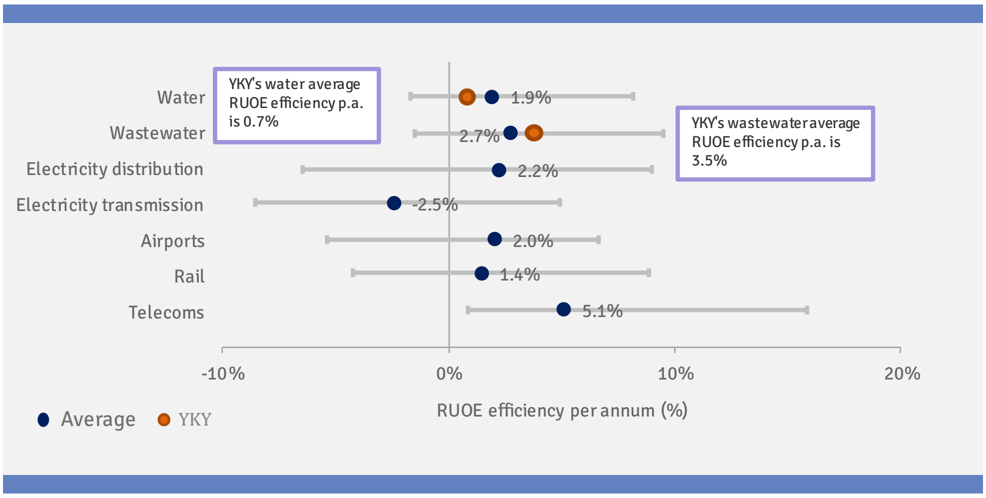
Table 26: RUOE efficiency savings per annum

Sector	Scale variable	Range	Average
Water	Total properties connected	-1.7% - 8.1%	1.9%
Yorkshire Water	Total properties connected	-6.1%- 4.6%	-0.7%
Wastewater	Total properties connected	-1.5% - 9.5%	2.7%
Yorkshire Wastewater	Total properties connected	-4.8% - 10.5%	3.5%
Electricity distribution	Number of customers	-6.4% - 9.0%	2.2%
Electricity transmission (National Grid)	Monthly average number employees	-8.5% - 4.9%	-2.5%
Airports	Terminal passengers handled	-5.4% - 6.7%	2.0%
Rail	Passenger km travelled	-4.2% - 8.9%	1.4%
Telco	Openreach total physical lines	0.8% - 15.9%	5.1%
Range		**-8.5% - 15.9%**	**-2.5% - 5.1%**

As shown in the results above, the range of results per sector is wide. For example, in the electricity distribution sector, average RUOE rose by 6.4% over 2013/14, indicating a decrease in efficiency. However, over 2016/17 the average RUOE reduction achieved by DNO's was 9.0%. The average RUOE reduction per annum for all firms across the period was 2.2%, indicating that generally, firms achieved improvements in efficiency between 2011/12 and 2016-17.

The above information is presented graphically in the figure overleaf.

Figure 32: Average RUOE efficiency savings per annum



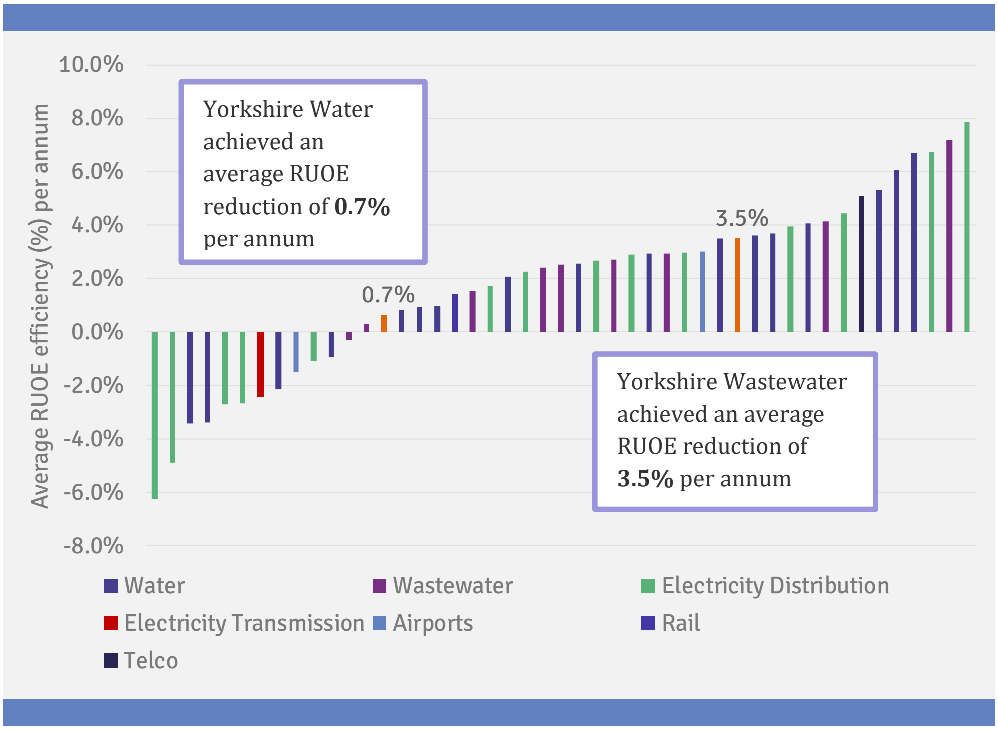
Source: Economic Insight

National Grid (electricity transmission) was the only sector to show an increase in average RUOE per annum over the period. Due to the limited number of observations for this sector (6) we decided to remove electricity transmission as an outlier.

After removing electricity transmission, the range of average efficiency gains across sectors is reduced to 1.4% to 5.1%.

The chart overleaf shows the average RUOE efficiency achieved over the 2011/12 to 2016/17 per company included in the analysis. As can be seen, Yorkshire Water is comfortably within the range of performance achieved by firms across comparable sectors. Yorkshire Water achieved an average RUOE efficiency score of 0.7% per annum over the period, while Yorkshire Wastewater achieved an average of 3.5% per annum, nearer the upper end of performance

Figure 33: Average RUOE efficiency savings per annum, by company



Source: Economic Insight

9.4 Choice of scale variable

In arriving at the results of this analysis, an important factor considered was the choice of scale variable. During the process of data collection, we ensured to gather data on a significant number of cost drivers per sector, in order to examine the difference choice of scale variable has on the perceived changes in efficiency.

For the water sector alone, we gathered data for total length of potable mains (km), the population served (000s), the total number of properties connected (000s), the amount of water delivered (potable + non-potable Ml/d), and distribution input (Ml/d), per company for each year. We calculated the RUOE measure using each of these scale variables. The average RUOE reduction obtained ranged from -3.2% to 3.0%, depending on the scale variable used. Similar variations in results were seen across all other sectors included in this analysis.

As a result, the choice of scale driver has a significant bearing on the final RUOE efficiency score per sector, and subsequently the perceived propensity for efficiency savings across regulated infrastructure networks in the UK. Deciding the scale variable upon was therefore an important part of our analysis.

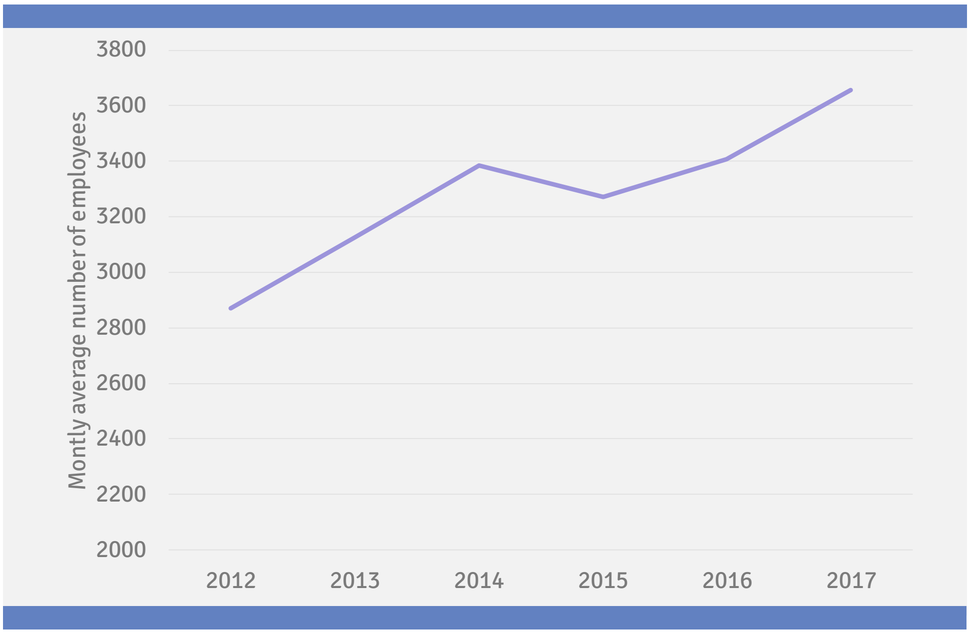
For the majority of sectors, we avoided using measures that relate to the physical size of the networks, such as length of potable mains (water) or track length (rail). This is because these measures fail to capture the increase in service from rising customer density or congestion, leaving the associated cost increases to be perceived as potential inefficiencies.

In certain cases, this was not possible. For example, for BT (telecommunications), we used Openreach total physical lines as our scale variable, as data for customer numbers was not available. Using this variable is likely to downplay the efficiency improvements of the telecommunications sector, which is expected to have achieved significant efficiency savings as a result of rapid technological change.

For electricity transmission, we decided to use the average number of employees per year, as opposed to units of electricity transmitted. Although throughout the existing literature, units of electricity transmitted is the preferred scale variable, the data over 2011/12 to 2016-17 is volatile, and thus in our view is unlikely to accurately represent unit cost trends. Instead, we have used the monthly average number of employees, which is an alternative measure for the scale of operations.

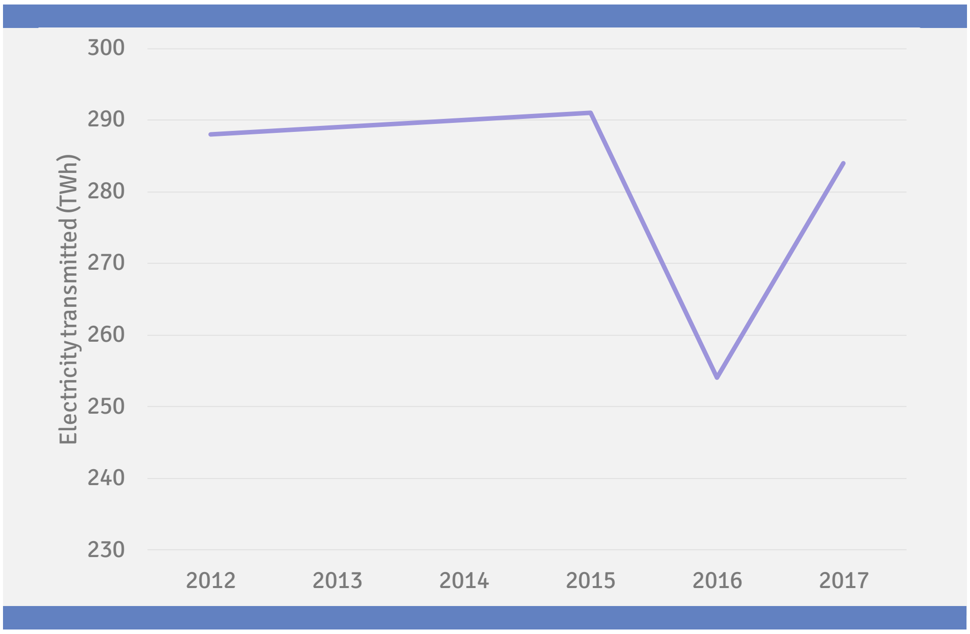
Below and overleaf, we chart the monthly average number of employees as well as the units of electricity distributed over time for the electricity sector over 2011/12 to 2016/17, to illustrate the differences between the two measures.

Figure 34: Monthly number of employees, National Grid



Source: Economic Insight

Figure 35: Electricity transmitted, National Grid



Source: Economic Insight

Therefore, when interpreting the results, care must be taken to account for the choice of scale variable used, and the potential implications of this choice on the implied comparative efficiency of sectors included in this analysis.

9.5 Sources

In the table below, we list the sources used to collect the data. Data was collected for each company over for each of the six years from 2011-12 to 2016-17.

Sector	Company	Sources
Water	Anglian water	Regulatory submissions published by Ofwat, entitled: ‘Ofwat stata master wholesale water’ Found at: https://www.ofwat.gov.uk/consultation/cost-assessment-pr19-consultation-econometric-modelling/
	Northumbrian Water	
	United Utilities	
	Southern Water	
	Severn Trent Water	
	South West Water	
	Thames Water	
	Welsh Water	
	Wessex Water	
	Yorkshire Water	
	Affinity Water	
	Bristol Water	
	Bournemouth Water	
	Dee Valley Water	
	Portsmouth Water	
	Sutton and East Surrey Water	
	South East Water	
	South Staffs Water	
Wastewater	Anglian Water	Regulatory submissions published by Ofwat, entitled: ‘Ofwat stata master wholesale wastewater’ Found at: https://www.ofwat.gov.uk/consultation/cost-assessment-pr19-consultation-econometric-modelling/
	Northumbrian Water	
	United Utilities	
	Southern Water	
	Severn Trent Water	
	South West Water	

	Thames Water	
	Welsh Water	
	Wessex Water	
	Yorkshire Water	
Electricity Distribution	Electricity North West Limited Company no: 02366949	Company accounts, sourced from Companies House, using corresponding company number. DPCR5 performance report 2010-2015 data table, published by Ofgem. Found at: https://www.ofgem.gov.uk/publications-and-updates/electricity-distribution-company-performance-2010-2015 RIIO electricity distribution annual report 2016-17 supplementary datafile, published by Ofgem. Found at: https://www.ofgem.gov.uk/publications-and-updates/riio-electricity-distribution-annual-report-2016-17 Electricity Distribution Annual report for 2008-09 and 2009-10, published by Ofgem. Found at: https://www.ofgem.gov.uk/publications-and-updates/electricity-distribution-annual-report-2008-09-and-2009-10
	Northern Powergrid (Northeast) Limited Company no: 02906593	
	Northern Powergrid (Yorkshire) plc Company no: 04112320	
	Scottish Hydro Electric Power Distribution plc Company no: SC213460	
	Southern Electric Power Distribution plc Company no: 04094290	
	SP Distribution plc Company no: SC189125	
	SP Manweb plc Company no: 02366937	
	London Power Networks plc Company no: 03929195	
	South Eastern Power Networks plc Company no: 03043097	
	Eastern Power Networks plc Company no: 02366906	
	Western Power Distribution (East Midlands) plc Company no: 02366923	
	Western Power Distribution (West Midlands) plc Company no: 03600574	

	Western Power Distribution (South West) plc Company no: 02366894 Western Power Distribution (South Wales) plc Company no: 02366985	
Electricity Transmission	National Grid Electricity Transmission plc	Company accounts, sourced from Companies House, using company number: 02366977 for cost data, and 04031152 for units transmitted.
Airports	Heathrow Company no: 01991017 Gatwick Company no: 01991018	Company accounts, sourced from Companies House, using corresponding company number.
Telecoms	BT Company no: 02216369	Company accounts, sourced from Companies House, using company number.

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