Appendix 8b:
Household retail efficiency benchmarking and triangulation

Author: Economic Insight

YorkshireWater

July 2018
Economic Insight Ltd

HOUSEHOLD RETAIL EFFICIENCY BENCHMARKING AND TRIANGULATION

A report for Yorkshire Water

CONTENTS

1. Executive Summary

This report provides estimates of the efficiency of Yorkshire Water's (Yorkshire's) household retail business. Our analysis brings together evidence of relative efficiency from Economic Insight, Oxera and Ofwat retail cost assessment models, to provide a plausible range.

1.1 Background

In PR19, Ofwat will set the efficiency challenge for companies' household retail businesses using an econometric benchmarking approach. This is a departure from the industry average cost to serve (ACTS) approach used in PR14, which effectively benchmarked companies against average unit costs, with adjustments for factors such as metering and economies and scope. In addition to the use of econometric models, Ofwat will also impose more aggressive efficiency challenges. Rather than the average benchmark used at PR14, companies will be benchmarked against the *'most efficient firms'.* Furthermore, Ofwat will not allow for a glide-path, but, rather will expect firms to be at the benchmark by the first year of PR19.

IN PR19, COMPANIES WILL BE BENCHMARKED AGAINST THE 'MOST EFFICIENT FIRMS'.

The novelty of an econometric approach within household retail means that there is no precedent to draw on as to the appropriate methodology. To help Yorkshire develop its business plan for PR19, Economic Insight provided evidence from our suite of 16 econometric cost models for the household retail control. In addition, Yorkshire also commissioned Oxera to develop its own cost models. As part of its May 2018 consultation on cost assessment for PR19, Ofwat invited companies to submit their retail cost models.[1] In total, 68 residential retail cost models were submitted. Ofwat stated that the final set of cost models will include 'high quality' models from this pool. Specifically, Ofwat stated that: *"the large pool of models and the stakeholder feedback will, in turn, help us select high quality models for cost assessment. The higher the quality of our models, the more confidence we can have in setting a stretching and appropriate efficiency challenge for companies[2].*"

In this context, Yorkshire asked us to bring together evidence from our own models and other sources. This report sets out the range of available evidence on the

[1] *Cost Assessment for PR19 – a consultation on econometric cost modelling.' Ofwat (May 2018).*
[2] *Cost Assessment for PR19 – a consultation on econometric cost modelling.' Ofwat (May 2018); page 6.*

efficiency performance of Yorkshire's retail business. This includes our own suite of econometric models, the models developed by Oxera, and Ofwat's own models – which we replicated using the dataset that was provided as part of the cost assessment consultation. We then draw conclusions about the implied plausible range for Yorkshire's retail efficiency challenge for PR19.

1.2 Key findings and conclusions

In presenting our key findings as to the appropriate efficiency challenge for Yorkshire's household retail business, we have considered two scenarios that correspond to Ofwat's desire to target the efficiency levels of the 'most efficient firms'. Our recommended benchmark is upper quartile performance, which we consider to be plausible, yet demanding. In addition, in view of Ofwat's more general desire for firms to submit 'challenging' business plans, we considered a more aggressive upper quintile benchmark.

Overall, we find that:

- Yorkshire's efficiency gap estimates to **upper quartile** are in the range of 0%[3] to 9.0% (average 1.5%) across total operating cost models; 0% to 17.3% (average 1.2%) across bad debt models; and 0% to 24.2% (average 7.0%) across non-bad debt cost models. Taken together, the bad debt and non-bad debt models imply a range of 0% to 21.3%.

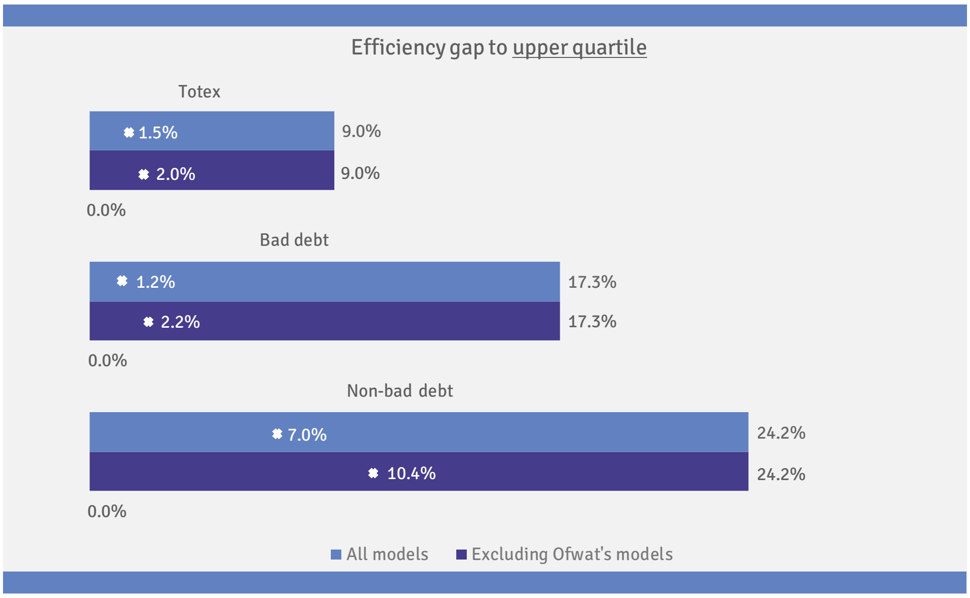
- Yorkshire's efficiency gap estimates to the more challenging **upper quintile** benchmark are in the range of 0% to 17.9% (average 3.9%) across total operating costs models; 0% to 19.8% (average 2.3%) across bad debt models; and 0% to 26.2% (average 7.9%) across non-bad debt cost models. Taken together, the bad debt and non-bad debt models imply a range of 0% to 23.6%.

In the figures overleaf, we present the range of efficiency gaps to upper quartile and quintile, across all models taken together, and excluding Ofwat's models. The white mark shows the estimate point average efficiency[4] gap across the models.

[3] For summary purposes here, we present the negative efficiency gaps as a 0% score. A negative efficiency gap is when Yorkshire performs better than the benchmark. Full estimates are included in Chapter 5.

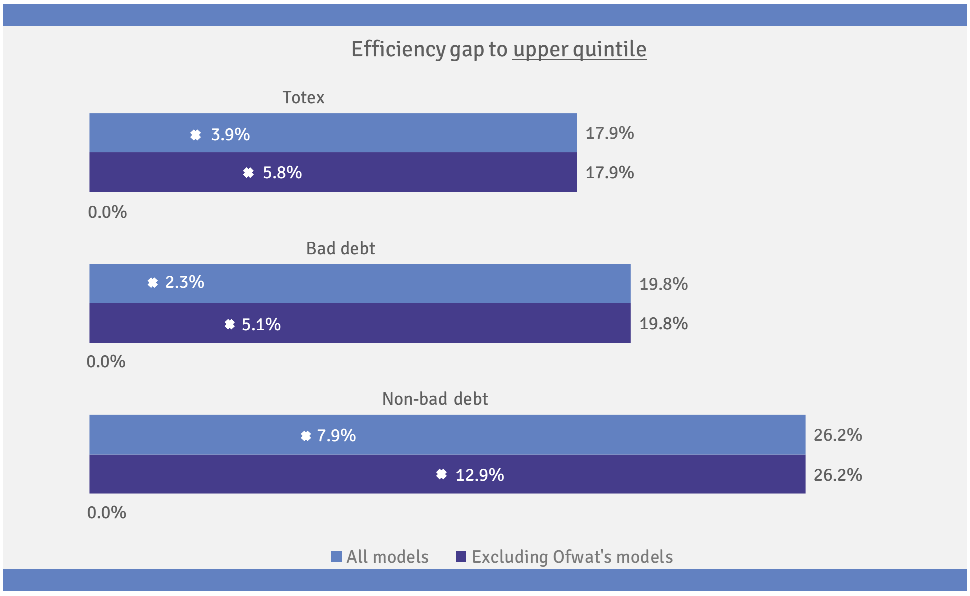
[4] The average efficiency gap is calculated across all models. Where Yorkshire performs better than the benchmark for certain models (i.e. negative efficiency gap), we consider it as a 0% gap, and take the average across the models accordingly.

Figure 1: Range of efficiency gap estimates to upper quartile



Source: Economic Insight analysis

Figure 2: Range of efficiency gap estimates to upper quintile



Source: Economic Insight analysis

1.3 Structure of this report

The report is structured as follows:

- Chapter 2 sets out our methodology for retail cost assessment in detail, and our resultant econometric models.
- Chapter 3 sets out Oxera's retail cost assessment models.
- Chapter 4 sets out Ofwat's retail cost assessment models.

- Chapter 5 discusses efficiency gap calculations and presents efficiency gap estimates for Yorkshire across Economic Insight, Ofwat and Oxera models.

2. Economic Insight Retail Models

This chapter summarises the suite of 16 econometric cost models that we developed for benchmarking the efficiency of companies' household retail businesses. We used a three-stage methodology to develop the econometric models, beginning with a first principles consideration of retail cost drivers, and then matching these drivers to available cost data. We then used a general to specific modelling approach to arrive at a suite of 16 econometric models, comprising eight separate models for total retail operating costs; and four models each for bad debt related retail operating costs and non-bad debt related retail operating costs.

2.1 Methodology

OUR METHODOLOGY BEGAN WITH A FIRST PRINCIPLES CONSIDERATION OF RETAIL COST DRIVERS.

Our suite of retail models originated from our work for Pelican Water (the joint retail arm of Wessex and Bristol Water). The background to this work is set out in our separate report, published by Ofwat as part of the responses to its consultation on cost assessment.[5] Our methodology for econometric retail cost modelling and the calculation of associated efficiency gaps uses a three-stage process to generate econometric cost models. We discuss each of these stages in turn:

- A first principles consideration of the drivers of retail operating costs.
- Matching of the retail cost drivers to available data.
- Econometric modelling, based on a general to specific approach.

2.1.1 First principles consideration of retail cost drivers

We began with a **first principles** consideration of the drivers of household retail costs. The approach to retail cost assessment at PR14 focused on unit cost benchmarking, with adjustments made to reflect meter penetration and economies of scope (in addition, company specific adjustments were subsequently made through special cost factor claims, mainly relating to bad debt and input price pressure). We

[5] *'Household retail cost assessment for PR19: a report for Bristol Water and Wessex Water.' Economic Insight (2018).*

therefore considered it important to assess the full range of potentially relevant drivers to be included within our econometric models. This is particularly important within an econometric framework, as failure to include a relevant cost driver can, in some circumstances, result in *omitted variable bias*.

The table below summarises our assessment of the main cost drivers for the household retail control. Note that, with respect to regional wages, we agree with Ofwat's assessment that this variable is unlikely to be statistically significant in an econometric retail cost model. For completeness, we included it within our initial generalised models to test this.

Table 1: Main drivers of household retail operating costs

Category	Driver	Rationale
Common cost drivers	Scale	Companies incur greater costs the more customers they serve.
	Scope	Companies undertake different tasks in serving dual service, water-only and wastewater-only customers.
	Regional wages	Test hypothesis that regional wage effects not significant in regression.
	Service quality	Cost-quality trade-off implies efficient company cannot reduce costs without lowering quality.
Bad debt	Regional socioeconomics	Customers with lower incomes and/or in financial difficulties are more likely to fall into arrears or default on bills.
	Wholesale bill size	Higher bills are associated with a greater cost in the event of the customer defaulting.
	Population transience	Debt management may be more difficult when customers have greater propensity to move around. Broader account management costs may also be impacted by transience.
Metering	Meter penetration	Additional tasks associated with metered customers imply higher costs.
	Meter density	Costs of serving metered customers likely to be lower if metered properties are closely located.
	Housing stock	Time taken to read water meters likely to differ depending on the type of housing.
	Congestion	Lower traffic speeds likely to result in meter reads being more time consuming.
	Population transience	Potential for greater account management costs associated with high population turnover.

Source: Economic Insight

2.1.2 Matching of drivers to available data

WE MATCHED COST DRIVERS TO AVAILABLE DATA.

Having established the key cost drivers to be included within the econometric models, we **matched them to available data.** This covered a range of sources, including the company data share, socioeconomic information from the Office for National Statistics (ONS), and traffic data from the Department for Transport (DfT). Where necessary, we mapped the data at the local authority level to company supply areas, using population-weighted overlaps between local authority areas and company supply areas. The table below summarises the measures that we used.

Table 2: Cost drivers selected for relevant measures

Driver	Measure	Source
Scale	Number of single service customers & number of dual service customers AND Total number of customers & number of single service customers	Company data share
Scope		
Regional wages	ASHE regional estimates for 'sales-related occupations'	ONS
Population transience	Population inflows and outflows relative to population	ONS
Service quality	SIM billing score	Ofwat
Meter penetration	Proportion of metered households	Company data share
Meter density	Number of metered households relative to mains length	Company data share
Housing stock	Percentage of flats	ONS
Congestion	Average peak traffic speed on A roads	DfT
Regional socioeconomics	IMD income score; property repossessions; house price-income ratio	ONS
Wholesale bill size	Average wholesale bill	Company data share

Source: Economic Insight

We draw attention to the following issues.

- Scale and scope, although conceptually separate issues, are very closely linked, and it is impossible in practice to measure them separately from each other. As such, we have explored two different ways of incorporating them within the model, which require slightly different measures. The first specification (A) uses separate variables for the number of dual and single service customers. The second specification (B) uses the total number of customers and the number of single service customers. We discuss this issue in further detail in the section below on general to specific modelling.

- We include three separate measures of regional socioeconomic performance: the Index of Multiple Deprivation (IMD) income measure; property repossessions; and house price to income ratio. We think each of these captures a distinct 'aspect' of the ways in which socioeconomics drive retail operating costs. The IMD income score is the percentage of the population entitled to certain income-related benefits. Property repossessions are intended as a measure of financial distress, while the house price to income ratio measures housing costs, relative to local incomes.

2.1.3 Econometric modelling

Several key methodological choices need to be made in developing econometric models. We summarise these choices in the table below, alongside the approaches we took.

Table 3: Key aspects of approach to econometric modelling

Methodological choice	Our approach
Dependent variable	Total retail operating costs; bad debt related retail operating costs; non-bad debt related retail operating costs.
Statistical significance	Strict general to specific; 'correct signs'.
Incorporation of panel structure	Pooled; random effects.
Estimation technique	Ordinary Least Squares (OLS); Generalised Least Squares (GLS).
Approach to scale and scope	Dual service customers and single service customers; and total customers and single service customers.

Source: Economic Insight

To align with Ofwat's indicated methodology, we used three different cost definitions as the dependent variable within our econometric models. We estimated top-down cost models, using **total retail operating costs** as the dependent variable, alongside bottom-up models for: i) **bad debt related retail operating costs**, including doubtful debt and debt management; and ii) **non-bad debt related operating costs**, including metering, customer service, depreciation and other costs.

General to specific modelling begins with a generalised econometric model that includes the full range of potentially relevant variables. Statistically insignificant variables are then eliminated one-by-one, beginning with the least significant variable. To strike an appropriate balance with intuition as to the important cost drivers, our approach to statistical significance was relatively 'liberal'. As such, we retained variables that were statistically significant at values approaching 10%. We also estimated alternative versions of the total retail operating cost models, which included variables that were not statistically significant, but were appropriately signed.

The dataset has a panel structure, with observations across 18 companies over 5 years from 2012/13 to 2016/17. In a similar manner to the PR14 wholesale econometric modelling, we incorporated this in two ways: i) we pooled the observations, effectively treating them as a cross section, using OLS; ii) we estimated random effects models using GLS.

WE EXPLORED TWO WAYS OF INCORPORATING SCALE AND SCOPE WITHIN THE ECONOMETRIC MODELS. BOTH HAVE ADVANTAGES AND DISADVANTAGES, AND CAN LEAD TO MATERIALLY DIFFERENT EFFICIENCY ESTIMATES.

As we described above, we explored two separate ways of incorporating scale and scope within the econometric models.

- **Model set A** includes single and dual service customers as separate variables within the models. This is a flexible specification that allows changes in single and dual customer numbers to have entirely separate impacts on costs. The resulting models include a larger number of variables, reducing the risk of omitted variable bias. It does, however, have the disadvantage that several companies have no dual service customers, meaning that the coefficient on this variable will represent the average effect on costs of an increase in dual service customers across all companies, including some that do not have such customers.

- **Model set B** uses an alternative specification, with separate variables for the total number of customers and the number of single service customers. This specification is less flexible, but does result in more parsimonious models, with coefficients that are easier to interpret. The models also appear to fit the data better (although this is not necessarily an advantage, since a priori one cannot distinguish between inefficiency and model specification problems). Further, as the models tend to include fewer explanatory variables, there may be greater risk of omitted variable bias.

Overall, both approaches have advantages and disadvantages and we do not think that there are strong reasons to consider either approach more credible than the other – though as we show subsequently, they do result in materially different efficiency score estimates for some companies.

Bringing these choices together, we estimated 16 econometric cost models in total, as summarised in the table overleaf.

Table 4: Updated suite of econometric cost models

Model	Dependent variable	Panel structure	Estimation technique	General to specific approach	Approach to number of customers
A1	Total retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Separate dual and single service customer variables
A2	Bad debt related retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Separate dual and single service customer variables
A3	Non-bad debt related retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Separate dual and single service customer variables
A4	Total retail operating costs	Pooled	Ordinary Least Squares	Alternative approach	Separate dual and single service customer variables
A5	Total retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Separate dual and single service customer variables
A6	Bad debt related retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Separate dual and single service customer variables
A7	Non-bad debt related retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Separate dual and single service customer variables
A8	Total retail operating costs	Random effects	Generalised Least Squares	Alternative approach	Separate dual and single service customer variables
B1	Total retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Total customers; single service customers
B2	Bad debt related retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Total customers; single service customers
B3	Non-bad debt related retail operating costs	Pooled	Ordinary Least Squares	Statistical significance	Total customers; single service customers
B4	Total retail operating costs	Pooled	Ordinary Least Squares	Alternative approach	Total customers; single service customers
B5	Total retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Total customers; single service customers
B6	Bad debt related retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Total customers; single service customers
B7	Non-bad debt related retail operating costs	Random effects	Generalised Least Squares	Statistical significance	Total customers; single service customers
B8	Total retail operating costs	Random effects	Generalised Least Squares	Alternative approach	Total customers; single service customers

Source: Economic Insight

2.2 Econometric models

In this section, we provide full details of the suite of 16 econometric models described above.

2.2.1 Model set A

The table below presents the pooled OLS models from model set A (models A1 to A4), which include separate dual and single service customer variables. These models have the following functional forms.

$$\text{A1: } \ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{flats}_{it} + \beta_4\, \textit{IMD income}_{it} + \beta_5 \ln(\textit{average wholesale bill}_{it}) + \varepsilon_{it}$$

$$\text{A2: } \ln(\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{IMD income}_{it} + \beta_4 \ln(\textit{average wholesale bill}_{it}) + \beta_5\, \textit{internal migration}_{it} + \varepsilon_{it}$$

$$\text{A3: } \ln(\text{non-}\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4\, \textit{metered household density}_{it} + \beta_5 \ln(\textit{peak traffic speed}_{it}) + \varepsilon_{it}$$

$$\text{A4: } \ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4\, \textit{metered household density}_{it} + \beta_5\, \textit{flats}_{it} + \beta_6 \ln(\textit{peak traffic speed}_{it}) + \beta_7\, \textit{IMD income}_{it} + \beta_8 \ln(\textit{average wholesale bill}_{it}) + \varepsilon_{it}$$

Table 5: Model set A – pooled OLS models (robust standard errors)

Model / Variables	Model A1 Total costs (ln)	Model A2 Bad debt costs (ln)	Model A3 Non-bad debt costs (ln)	Model A4 Total costs (ln)
Single service customers (ln)	0.536*** (0.0464)	0.535*** (0.0696)	0.498*** (0.0639)	0.563*** (0.0678)
Dual service customers (ln)	0.122*** (0.0192)	0.121*** (0.0273)	0.263*** (0.0112)	0.159*** (0.0204)
Metered households (%)			0.0143*** (0.00369)	0.00723* (0.00382)
Metered to mains length (%)			-0.0155*** (0.00437)	-0.00662** (0.00318)
Proportion flats (%)	0.0571*** (0.0107)			0.0604*** (0.0170)
Peak traffic speed (ln)			-1.830*** (0.308)	-0.364 (0.342)
IMD income (%)	0.164*** (0.0199)	0.189*** (0.0204)		0.155*** (0.0280)
Wholesale bill	1.206*** (0.116)	1.744*** (0.202)		0.999*** (0.140)
Total internal migration (%)		0.0909*** (0.0264)		
Constant	-10.02*** (0.815)	-14.37*** (1.334)	4.539*** (1.090)	-8.063*** (1.909)
Observations	89	89	89	89
R-squared	0.932	0.937	0.881	0.935

*Source: Economic Insight, ***p<0.01, ** p<0.05, * p<0.1*

The table below presents the random effects models from model set A (models A5 to A8). These models have the following functional forms.

A5: $\ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{IMD income}_{it} + \beta_4\, \textit{property repossessions}_{it} + \beta_5 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

A6: $\ln(\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{IMD income}_{it} + \beta_4 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

A7: $\ln(\text{non-}\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4 \ln(\text{peak traffic speed}_{it}) + \beta_5\, \textit{time trend}_t + u_i + v_{it}$

A8: $\ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{single service customers}_{it}) + \beta_2 \ln(\textit{dual service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4\, \textit{flats}_{it} + \beta_5\, \textit{IMD income}_{it} + \beta_6\, \textit{property repossessions}_{it} + \beta_7 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

Table 6: Model set A – random effects models (robust standard errors)

Model / Variables	Model A5 Total costs (ln)	Model A6 Bad debt costs (ln)	Model A7 Non-bad debt costs (ln)	Model A8 Total costs (ln)
Single service customers (ln)	0.349*** (0.105)	0.532*** (0.120)	0.268** (0.120)	0.318*** (0.108)
Dual service customers (ln)	0.226*** (0.0434)	0.184*** (0.0618)	0.250*** (0.0315)	0.246*** (0.0452)
Metered households (%)			0.00214 (0.00420)	0.00198 (0.00294)
Proportion flats (%)				0.0526 (0.0360)
Peak traffic speed (%)			-1.217** (0.611)	
IMD income (%)	0.0657 (0.0475)	0.136*** (0.0516)		0.105* (0.0547)
Property repossessions (%)	0.107*** (0.0289)			0.119*** (0.0383)
Wholesale bill (ln)	0.341 (0.238)	1.235*** (0.405)		0.301 (0.241)
Trend			-0.0372** (0.0151)	
Constant	-2.741 (1.679)	-10.25*** (2.620)	4.104* (2.242)	-3.836** (1.860)
Observations	89	89	89	89
Groups	18	18	18	18

*Source: Economic Insight, ***p<0.01, ** p<0.05, * p<0.1*

2.2.2 Model set B

The table below presents the pooled OLS models from model set B (models B1 to B4), which include separate total and single service customer variables. These models have the following functional forms.

$$B1: \ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2\, \textit{IMD income}_{it} + \beta_3\, \textit{property repossessions}_{it} + \beta_4 \ln(\textit{average wholesale bill}_{it}) + \varepsilon_{it}$$

$$B2: \ln(\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2\, \textit{IMD income}_{it} + \beta_3 \ln(\textit{average wholesale bill}_{it}) + \varepsilon_{it}$$

$$B3: \ln(\text{non-}\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2 \ln(\textit{single service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4 \ln(\text{peak traffic speed}_{it}) + \varepsilon_{it}$$

$$B4: \ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2 \ln(\textit{single service customers}_{it}) + \beta_3\, \textit{metered properties}_{it} + \beta_4\, \textit{IMD income}_{it} + \beta_5\, \textit{property repossessions}_{it} + \beta_6 \ln(\textit{average wholesale bill}_{it}) + \varepsilon_{it}$$

Table 7: Model set B – pooled OLS models (robust standard errors)

Model / Variables	Model B1 Total costs (ln)	Model B2 Bad debt costs (ln)	Model B3 Non-bad debt costs (ln)	Model B4 Total costs (ln)
Total customers (ln)	0.877*** (0.0211)	0.979*** (0.0435)	1.061*** (0.0192)	0.966*** (0.0471)
Single service customers (ln)			-0.120*** (0.0206)	-0.0690* (0.0398)
Metered households (%)			0.00452*** (0.00151)	0.00473*** (0.00163)
Peak speed (ln)			-0.257* (0.136)	
IMD income (%)	0.0273*** (0.00790)	0.0668*** (0.0148)		0.0274*** (0.00888)
Property repossessions (%)	0.121*** (0.0267)			0.147*** (0.0247)
Wholesale bill (ln)	0.659*** (0.0348)	1.091*** (0.0661)		0.480*** (0.0814)
Constant	-6.974*** (0.166)	-11.31*** (0.342)	-3.200*** (0.500)	-6.502*** (0.394)
Observations	89	89	89	89
R-squared	0.983	0.963	0.969	0.985

*Source: Economic Insight, ***p<0.01, ** p<0.05, * p<0.1*

The table below presents the random effects models from model set B (models B5 to B8). These models have the following functional forms.

B5. $\ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2 \ln(\textit{single service customers}_{it}) + \beta_3\, \textit{property repossessions}_{it} + \beta_4 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

B6. $\ln(\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2\, \textit{IMD income}_{it} + \beta_3\, \textit{property repossessions}_{it} + \beta_4 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

B7. $\ln(\text{non-}\textit{bad debt related operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2 \ln(\textit{single service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4 \ln(\text{peak traffic speed}_{it}) + \beta_5\, \text{time trend}_t + u_i + v_{it}$

B8. $\ln(\textit{total retail operating costs}_{it}) = \beta_0 + \beta_1 \ln(\textit{total customers}_{it}) + \beta_2 \ln(\textit{single service customers}_{it}) + \beta_3\, \textit{metered households}_{it} + \beta_4\, \textit{property repossessions}_{it} + \beta_5 \ln(\textit{average wholesale bill}_{it}) + u_i + v_{it}$

Table 8: Model set B – random effects models (robust standard errors)

Model / Variables	Model B5 Total costs (ln)	Model B6 Bad debt costs (ln)	Model B7 Non-bad debt costs (ln)	Model B8 Total costs (ln)
Total customers (ln)	1.043*** (0.0773)	0.933*** (0.0921)	1.069*** (0.0518)	1.065*** (0.0821)
Single service customers (ln)	-0.134** (0.0656)		-0.138** (0.0600)	-0.150** (0.0692)
Metered households (%)			0.00461 (0.00291)	0.00201 (0.00239)
Peak speed (ln)			-0.327 (0.306)	
IMD income (%)		0.0553* (0.0306)		
Property repossessions (%)	0.113*** (0.0263)	0.147** (0.0600)		0.130*** (0.0332)
Wholesale bill (ln)	0.400*** (0.138)	1.165*** (0.189)		0.351** (0.149)
Time trend			-0.0349*** (0.0112)	
Constant	-5.519*** (0.640)	-11.57*** (0.789)	-2.820** (1.104)	-5.446*** (0.655)
Observations	89	89	89	89
Groups	18	18	18	18

*Source: Economic Insight, ***p<0.01, ** p<0.05, * p<0.1*

3. Oxera Retail Models

In this chapter, we summarise the econometric models that Oxera developed for Yorkshire. We first describe Oxera's methodology, including their approach to model selection, before going on to set out the econometric models that Oxera developed in greater detail.

3.1 Methodology

3.1.1 Overall approach

Oxera based its analysis on a dataset covering 2013/14 to 2015/16. The use of a starting date of 2013/14 is consistent with Ofwat's analysis. Oxera modelled a range of dependent variables. Some of these categories are more granular than the broader cost categories that Ofwat used in its own models. These included:

- BOTEX (base totex – equivalent to 'total retail operating costs');
- doubtful debt and debt management costs;
- BOTEX net of doubtful debt and debt management costs;
- customer services costs; and
- BOTEX net of bad debt and customer services costs.

As with Economic Insight's approach, Oxera used log-linear regression specifications across all models. For the purpose of statistical inference, Oxera used heteroscedasticity-robust standard errors to determine the level of statistical significance. Again, this is consistent with Economic Insight's approach.

Oxera used a 'traffic light' approach to model selection. A model is rated green if it passes all tests, amber if it passes some tests and fail others, and red if it fails one test - such that all other relevant tests also fail (for example, functional form). Additionally, the traffic light system is used to give an assessment across the following metrics: number of outliers; interpretable results; and significant coefficients. Oxera excluded models that scored 'red' on any metric from their triangulation exercise.

3.1.2 Cost drivers

Oxera distinguished between 'main' and 'alternative' models. Its main models all used the (log of the) number of unique customers to account for the impact of scale on retail operating costs. We summarise the cost drivers, and the measures included in Oxera's main models in the table below.

Table 9: Cost drivers and measures included in Oxera's models

Dependent variable	Cost driver	Measures
BOTEX	Scale	Number of unique customers (log)
BOTEX	Bill size	Average bill
BOTEX	Population transience	Population turnover (%)
BOTEX	Deprivation	Income deprivation (from Index of Multiple Deprivation); overall deprivation (from Index of Multiple Deprivation, Wales excluded); unemployment rate; and an alternative deprivation measure from PR14
Doubtful debt & debt management	Scale	Number of unique customers (log)
Doubtful debt & debt management	Bill size	Average bill
Doubtful debt & debt management	Population transience	Population turnover (%)
Doubtful debt & debt management	Deprivation	Income deprivation (from Index of Multiple Deprivation); overall deprivation (from Index of Multiple Deprivation, Wales excluded); unemployment rate; and an alternative deprivation measure from PR14
BOTEX less bad debt	Scale	Number of unique customers (log)
BOTEX less bad debt	Meter penetration	Proportion metered customers
BOTEX less bad debt	Complaints	Number of complaints per customer
BOTEX less bad debt	Population transience	Transient population (%)
Customer services/other retail costs	Scale	Number of unique customers (log)
Customer services/other retail costs	Meter penetration	Proportion metered customers

Source: Oxera

In a number of cases, Oxera estimated 'alternative' models that used different variables to account for scale (customer numbers) and deprivation. The alternative deprivation variables included in Oxera's retail cost assessment models are as follows:

- Income deprivation – All LSOAs excluding Wales
- Income deprivation - 25%; 50%; and 75% most deprived LSOAs
- Multiple deprivation – All LSOAs
- Multiple deprivation – 25%; 50%; and 75% most deprived LSOAs

Oxera also tested the use of alternative scale variables to the (log of) the number of unique customers. The alternative scale variables are listed in the following table, where each cell contains the variables that are included together in a single model.

Table 10: Economies of scale variables used in Oxera's retail cost assessment models

Economies of scale variables
Dual customers, served by WASC Single customers, served by WOSC Single customers, served by WOC
Water only customers, served by WASC Sewerage only customers, served by WASC Water only customers, served by WOC Dual customers, served by WASC
Water customers, served by WASC Sewerage customers, served by WASC Water customers, served by WOC
Customers, served by WOSC Customers, served by WOC
Customers Proportion of dual billed customers

Source: Oxera

3.2 Econometric models

3.2.1 BOTEX models

As discussed above, Oxera estimated three sets of models for BOTEX, which we set out in full below:

- main models;
- models with alternative assumptions on deprivation; and
- models with alternative estimates for economies of scope.

3.2.1.1 BOTEX main models

The table below presents Oxera's 'main' BOTEX models.

Table 11: BOTEX main models results

Model	BOTEX1	BOTEX2	BOTEX3	BOTEX4
Dependent variable / variables	BOTEX (log)			
Unique customers (log)	0.879***	0.899***	0.934***	0.934***
Average bill (log)	0.430***	0.377***	0.372***	0.353***
Population turnover (%)	0.0550***	0.0794***	0.0127	0.0132
Income deprivation (log)- All LSOAs	0.752**			
Multiple deprivation (log)- All LSOAs, excl. Wales		0.761**		
Unemployment (rate)			0.0515	
Alternative PR14 deprivation				0.274
Constant	9.561***	5.654***	8.061***	9.056***
R^2	0.972	0.975	0.970	0.970
Number of outliers	1	4	2	0
Interpretable results				
Significant coefficients				
Diagnostic				
Included in triangulations				

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.1.2 BOTEX models including alternative deprivation measures

The table below presents Oxera's BOTEX models with alternative measures of deprivation.

Table 12: Oxera BOTEX alternative deprivation variables models results

Model	BOTEX5	BOTEX6	BOTEX7	BOTEX8	BOTEX9	BOTEX10	BOTEX11
Dependent variable / variables	BOTEX (log)						
Unique customers (log)	0.906***	0.880***	0.878***	0.889***	0.908***	0.885***	0.867***
Average bill (log)	0.384***	0.424***	0.432***	0.440***	0.361***	0.395***	0.454***
Population turnover (%)	0.0596***	0.0494***	0.0427**	0.0404**	0.0711***	0.0751***	0.0854***
Income deprivation (log)- All LSOAs, excl. Wales	0.661**						
Income deprivation (log)- 75% most deprived LSOAs		0.587**					
Income deprivation (log)- 50% most deprived LSOAs			0.392**				
Income deprivation (log)- 25% most deprived LSOAs				0.214*			
Multiple deprivation (log)- 75% most deprived LSOAs					0.563**		
Multiple deprivation (log)- 50% most deprived LSOAs						0.454***	
Multiple deprivation (log)- 25% most deprived LSOAs							0.315**
Constant	9.370***	9.376***	9.088***	8.681***	6.411***	6.776***	7.012***
R^2	0.974	0.972	0.972	0.971	0.974	0.975	0.975
Number of outliers	4	1	1	1	4	4	4
Interpretable results							
Significant coefficients							
Diagnostic							
Included in triangulations							

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.1.3 BOTEX models including alternative scale measures

The table below presents Oxera's BOTEX models with alternative scale measures.

Table 13: Oxera BOTEX alternative estimates of economies of scope models results

Model	BOTEX12	BOTEX13	BOTEX14	BOTEX15	BOTEX16
Dependent variable / variables	BOTEX (log)				
Average bill (log)	0.642***	0.717***	0.608***	0.539***	0.408***
Population turnover (%)	0.0578**	0.0829***	0.0631***	0.0432**	0.0561**
Income deprivation (log)-All LSOAs	0.565*	0.849***	0.941***	0.819**	0.780**
Dual customers, served by WASC (log)	0.819***	0.769***			
Single customers, served by WASC (log)	0.0874				
Single customers, served by WOC (log)	0.844***				
Water only customers, served by WASC (log)		0.00667			
Sewerage only customers, served by WASC (log)		0.0523*			
Water only customers, served by WOC (log)		0.763***			
Water customers, served by WASC (log)			0.219		
Sewerage customers, served by WASC (log)			0.637***		
Water customers, served by WOC (log)			0.836***		
Customers, served by WOC (log)				0.904***	
Customers, served by WASC (log)				0.902***	
Customers (log)					0.869***
Dual billed customers (proportion)					0.245*
Constant	8.305***	8.769***	9.270***	9.140***	9.772***
R^2	0.970	0.971	0.976	0.971	0.972
Number of outliers	0	0	0	0	0
Interpretable results					
Significant coefficients					
Diagnostics					
Included in triangulation					

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.2 Doubtful debt models

Similar to the BOTEX models, Oxera estimated three sets of models for doubtful debt and debt management: the main models; models with alternative deprivation measures; and models with alternative estimates for economies of scope.

3.2.2.1 Doubtful debt and debt management main models

The table below presents Oxera's main doubtful debt and debt management models.

Table 14: Oxera doubtful debt and debt management main models

Model	Bad debt 1	Bad debt 2	Bad debt 3	Bad debt 4
Dependent variable / variables	Doubtful debt and debt management (log)			
Unique customers (log)	0.904***	0.893***	0.953***	0.853***
Average bill (log)	0.893***	0.854***	0.853***	0.888***
Population turnover (%)	0.0407	0.105***		0.0162
Income deprivation (log)- All LSOAs	0.959**			
Multiple deprivation (log)- All LSOAs, excl. Wales		1.284***		
Unemployment (rate)			0.0858*	
Alternative PR14 deprivation				0.937***
Constant	6.379***	0.232	4.172***	7.014***
R^2	0.956	0.964	0.954	0.962
Number of outliers	1	3	2	1
Interpretable results				
Significant coefficients				
Diagnostic				
Included in triangulations				

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.2.2 Doubtful debt and debt management alternative deprivation measures models

The table below shows Oxera's doubtful debt and debt management models, including alternative deprivation variables.

Table 15: Oxera doubtful debt and debt management models including alternative deprivation variables

Model	Bad debt 5	Bad debt 6	Bad debt 7	Bad debt 8	Bad debt 9	Bad debt 10	Bad debt 11	Bad debt 12
Dependent variable / variables	Doubtful debt and debt management (log)							
Unique customers (log)	0.953***	0.906***	0.929***	0.966***	0.893***	0.889***	0.889***	0.864***
Average bill (log)	0.812***	0.885***	0.868***	0.842***	0.854***	0.844***	0.864***	0.950***
Population turnover (%)	0.0490	0.0334	0.0150	0.00220	0.105***	0.102***	0.0881**	0.102**
Income deprivation (log)- All LSOAs, excl. Wales	0.790*							
Income deprivation (log)- 75% most deprived LSOAs		0.747**						
Income deprivation (log)- 50% most deprived LSOAs			0.408*					
Income deprivation (log)- 25% most deprived LSOAs				0.168				
Multiple deprivation (log)- All LSOAs, excl. Wales					1.284***			
Multiple deprivation (log)- 75% most deprived LSOAs						1.053***		
Multiple deprivation (log)- 50% most deprived LSOAs							0.692***	
Multiple deprivation (log)- 25% most deprived LSOAs								0.474***
Constant	6.018***	6.139***	5.628***	5.147***	0.232	1.141	2.384***	2.776***
R^2	0.960	0.956	0.955	0.953	0.964	0.964	0.963	0.962
Number of outliers	4	1	1	1	3	4	4	3
Interpretable results								
Significant coefficients								
Diagnostic								
Included in triangulations								

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.2.3 Doubtful debt and debt management alternative estimates for economies of scope models

The table below shows Oxera's doubtful debt and debt management models, including alternative scale variables.

Table 16: Oxera doubtful debt and debt management alternative estimates for economies of scope models results

Model	Bad debt 13	Bad debt 14	Bad debt 15	Bad debt 16	Bad debt 17
Dependent variable / variables	Doubtful debt and debt management (log)				
Average bill (log)	0.996***	1.115***	0.985***	0.879***	0.808***
Population turnover (%)	0.0587	0.0880**	0.0709*	0.0393	0.0486
Income deprivation (log)-All LSOAs	0.953**	1.412***	1.597***	1.071**	0.969**
Dual customers, served by WASC (log)	0.777***	0.711***			
Single customers, served by WASC (log)	0.101				
Single customers, served by WOC (log)	0.785***				
Water only customers, served by WASC (log)		-0.0473			
Sewerage only customers, served by WASC (log)		0.0647*			
Water only customers, served by WOC (log)		0.652***			
Water customers, served by WASC (log)			-0.0223		
Sewerage customers, served by WASC (log)			0.806***		
Water customers, served by WOC (log)			0.740***		
Customers, served by WOC (log)				0.874***	
Customers, served by WASC (log)				0.901***	
Customers (log)					0.877***
Dual billed customers (proportion)					0.382
Constant	6.399***	7.307***	7.981***	6.893***	6.900***
R^2	0.950	0.952	0.959	0.956	0.956
Number of outliers	1	1	1	1	1
Interpretable results					
Significant coefficients					
Diagnostics					
Included in triangulation					

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.3 Customer service and other costs models

Here, Oxera estimates models for: (i) BOTEX net of doubtful debt and debt management; (ii) customer service costs; and (iii) BOTEX net of bad debt and customer service costs. For BOTEX net of bad debt costs, models with alternative estimates for economies of scope are also estimated.

3.2.3.1 BOTEX less bad debt main models

The table below presents Oxera's main BOTEX less bad debt models.

Table 17: Oxera BOTEX less bad debt models results

Model	Non-bad debt 1	Non-bad debt 2	Non-bad debt 3	Non-bad debt 4
Dependent variable / variables	BOTEX less doubtful debt and debt management			
Unique customers (log)	0.981***	0.987***	0.989***	0.934***
Metering penetration (proportion)		0.541***		
Number of complaints per customer (#)				0.786***
Transient population (%)			0.0183	
Constant	9.730***	9.428***	9.482***	9.826***
R^2				0.970
Number of outliers	1	1	0	1
Interpretable results				
Significant coefficients				
Diagnostic				
Included in triangulations				

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.3.2 BOTEX less bad debt models including alternative scale variables

The table below presents Oxera's models for BOTEX less bad debt costs, including alternative scale variables.

Table 18: Oxera BOTEX less bad debt alternative estimates for economies of scope models results

Model	Non-bad debt 5	Non-bad debt 6	Non-bad debt 7	Non-bad debt 4	Non-bad debt 5
Dependent variable / variables	BOTEX less doubtful debt and debt management				
Dual customers, served by WASC (log)	0.881***	0.885***			
Single customers, served by WASC (log)	0.160***				
Single customers, served by WOC (log)	0.941***				
Water only customers, served by WASC (log)		0.0554			
Sewerage only customers, served by WASC (log)		0.0611*			
Water only customers, served by WOC (log)		0.882***			
Water customers, served by WASC (log)			0.422***		
Sewerage customers, served by WASC (log)			0.595***		
Water customers, served by WOC (log)			0.975***		
Customers, served by WOC (log)				1.030***	
Customers, served by WASC (log)				1.040***	
Customers (log)					1.000***
Dual billed customers (proportion)					0.181**
Constant	10.01***	10.38***	9.796***	9.446***	9.618***
R^2	0.945	0.935	0.948	0.945	0.947
Number of outliers	0	0	1	0	0
Interpretable results					
Significant coefficients					
Diagnostics					
Included in triangulation					

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

3.2.3.3 Customer service and other costs models

The table below shows Oxera's customer services cost models.

Table 19: Oxera customer service model results

Model	Model 1	Model 2
Dependent variable / variables	Customer service (log)	
Unique customers (log)	0.985***	0.989***
Metering penetration (proportion)		0.355
Constant	8.869***	8.670***
R^2	0.927	0.930
Number of outliers	4	2
Interpretable results		
Significant coefficients		
Diagnostic		
Included in triangulations		

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

The table below shows Oxera's models of other retail costs.

Table 20: Other costs model results

Model	Model 1	Model 2
Dependent variable / variables	BOTEX less (doubtful debt + debt management + customer service) (log)	
Unique customers (log)	0.986***	0.995***
Metering penetration (proportion)		0.671***
Constant	9.095***	8.720***
R^2	0.920	0.930
Number of outliers	1	1
Interpretable results		
Significant coefficients		
Diagnostic		
Included in triangulations		

*Source: Oxera, ***p<0.01, ** p<0.05, * p<0.1*

4. Ofwat Retail Models

This chapter summarises the econometric models that Ofwat presented as part of its consultation on the approach to cost assessment at PR19. Ofwat included 14 models, including: four total operating costs models; six bad debt models; and four total operating costs less bad debt models.

4.1 Methodology

In March 2018, Ofwat published a consultation on econometric cost modelling for PR19. As part of its consultation, Ofwat has published 14 residential retail cost models. In this section we summarise Ofwat's methodological choice for the models.

4.1.1 Cost aggregation

In line with indications in the final PR19 methodology, Ofwat's models included three types of dependant variable, at two levels of aggregation:

- An 'aggregated model' of total retail costs (RTC).
- 'Disaggregated models' of: i) bad debt plus debt management costs (RDC); and ii) other retail costs (ROC).

Ofwat said that its choice of cost categories as dependent variables in the disaggregated models was motivated by several factors, including: common cost drivers; data quality, particularly with respect to cost allocation; and interactions between activities. This was especially true of bad debt and debt management costs. Ofwat considered that estimating separate models for bad debt and debt management would allow it to better capture the relationship between these costs and 'unique drivers' such as bill size and deprivation. Nevertheless, Ofwat said that there were still potential trade-offs and cost allocation issues with the disaggregated categories, so also included total cost models.[6]

[6] *'Cost assessment for PR19: A consultation on econometric cost modelling.'* *Ofwat, p22-3.*

4.1.3 Data

Ofwat used data from the four years from 2013/14 to 2016/17. Most of the data came from companies' returns, though it did include external data in its bad debt models. These included:

- Deprivation measures, including income, unemployment, job-seekers' allowance and the index of multiple deprivation (IMD).
- Credit arrears risk data from Equifax.

4.1.4 Dependent variable

In all cases, the dependent variable was expressed as the cost per connected household, rather than total retail costs. Ofwat said that this was more intuitive, on the grounds that retail costs are 'primarily driven by the number of customers'.[7] To allow for economies of scale, Ofwat included the number of connected households in some models. We note that the practical effect of these choices is that, by assumption, companies' implied efficiency positions will be very similar to those that would be implied by an ACTS approach.

4.1.5 Explanatory variables

Ofwat set out what it considers to be the most important candidate cost drivers of household retail costs. We summarise these in the table below. In addition, we note that Ofwat included time dummies within its models.

Table 21: Ofwat's candidate retail cost drivers

Cost category	Driver	Expected to be cost driver
Bad debt and debt management; other retail costs	Total number of household customers	Yes
Bad debt and debt management	Average bill size	Yes
Bad debt and debt management	Propensity of default on payment	Yes
Bad debt and debt management	Changes in household occupancy (transience)	Yes
Other retail costs	Proportion of dual customers	Yes
Other retail costs	Proportion of metered household customers	Yes
Other retail costs	Density/sparsity of metered properties	Yes – but not included as did not perform well in practice
Other retail costs	Quality of retail service	Yes – but not included as did not perform well in practice
Other retail costs	Regional labour costs	No – can be 'substantially mitigated'

Source: Adapted from Ofwat

[7] *'Cost assessment for PR19: A consultation on econometric cost modelling.' Ofwat, p24.*

4.2 Econometric models

The remainder of this chapter summarises Ofwat's models.

4.2.1 Total operating costs models

The table below presents Ofwat's total retail cost models.

Table 22: Ofwat's total operating costs models

Model	ORTC1	ORTC2	ORTC3	ORTC4
Dependent variable / variables	Ln(total retail cost per household)			
% of dual service households	0.006*** (0.000)			
Ln(number of households)				-0.119** (0.012)
% metered households	0.005 (0.167)		0.004 (0.420)	0.004 (0.376)
Ln(bill size)		0.535*** (0.000)	0.468*** (0.000)	0.641*** (0.000)
% households with default (Eq_lpcf62)			0.026 (0.173)	0.042** (0.014)
2015 dummy	0.025 (0.344)	0.034 (0.156)	0.024 (0.344)	0.024 (0.372)
2016 dummy	-0.070** (0.046)	-0.029 (0.301)	-0.043 (0.265)	-0.029 (0.446)
2017 dummy	-0.133*** (0.001)	-0.090*** (0.003)	-0.096** (0.012)	-0.064* (0.094)
Constant	2.857***	0.361	-0.14	0.117
R2 adjusted	0.583	0.612	0.638	0.694
VIF (max)	1.513	1.494	2.019	2.936
Reset test	0.732	0.005	0.033	0.396
Estimation method	OLS	OLS	OLS	OLS
N (sample size)	71	71	71	71

Source: Ofwat

4.2.2 Bad debt models

The table below presents models ORDC1 to ORDC3 of Ofwat's bad debt models.

Table 23: Ofwat bad debt models ORDC1 to ORDC3

Ofwat model identifier	ORDC1	ORDC2	ORDC3
Dependent variable	Ln(bad debt per household)		
Ln(no. of households)			-0.128* (0.083)
Ln(bill size)	1.160*** (0.000)	1.138*** (0.000)	1.341*** (0.000)
HHs with default (%) (Eq_lpcf62)	0.050*** (0.006)		0.068*** (0.004)
Income deprivation domain (%)			
Credit risk score (Eq_rgc102)		-0.032** (0.034)	
Constant	-5.479***	0.393	-5.204***
R2 adjusted	0.79	0.773	0.803
VIF (max)	1.03	1.078	2.843
Reset test	0.146	0.257	0.153
Estimation method	OLS	OLS	OLS
N (sample size)	71	71	71

Source: Ofwat

The table below presents models ORDC4 to ORDC6 of Ofwat's bad debt models. We note that ORDC6, in contrast to all of Ofwat's other models, does not have a panel structure. Rather, it uses a cross-section, with variables expressed as the sample average over time.

Table 24: Ofwat bad debt models ORDC4 to ORDC6

Ofwat model identifier	ORDC4	ORDC5	ORDC6
Dependent variable	Ln(bad debt per household)		Ln(bad debt per household) - sample average
Ln(no. of households)	-0.032 (0.629)		-0.053 (0.601)
Ln(bill size)	1.183*** (0.000)	1.095*** (0.000)	1.168*** (0.000)
HHs with default (%) (Eq_lpcf62)			
Income deprivation domain (%)		0.058** (0.032)	
Credit risk score (Eq_rgc102)	-0.034** (0.034)		-0.036* (0.067)
Constant	0.888	-4.580***	1.467
R2 adjusted	0.771	0.774	0.789
VIF (max)	2.152	1.178	2.221
Reset test	0.352	0.018	0.477
Estimation method	OLS	OLS	OLS
N (sample size)	71	71	17

Source: Ofwat

4.2.3 Total operating costs less bad debt models

The table below presents Ofwat's total operating costs less bad debt models.

Table 25: Ofwat total operating costs less bad debt models

Ofwat model identifier	OROC1	OROC2	OROC3	OROC4
Dependent variable	Ln(other retail costs per household)			
% of dual service households	0.002 (0.132)	0.002 (0.115)	0.003** (0.01)	0.003** (0.016)
% metered households		0.004 (0.227)		0.004 (0.322)
Ln(number of households)			-0.080* (0.094)	-0.068 (0.208)
2015 dummy	0.036* (0.081)	0.026 (0.279)	0.036* (0.08)	0.028 (0.275)
2016 dummy	-0.048	-0.067	-0.047	-0.064
	(0.204)	(0.127)	(0.22)	(0.159)
2017 dummy	-0.078**	-0.101**	-0.069*	-0.090*
	(0.043)	(0.021)	(0.053)	(0.052)
Constant	2.752***	2.552***	3.784***	3.457***
R2 adjusted	0.06	0.124	0.117	0.162
VIF (max)	1.493	1.513	2.153	2.212
Reset test	0.497	0.819	0.315	0.907
Estimation method	OLS	OLS	OLS	OLS
N (sample size)	71	71	71	71

Source: Economic Insight

4.3 Our observations on Ofwat's models

Below, we set out our main observations on Ofwat's models for bad debt; non-bad debt; and total operating costs respectively.

- **Bad debt models.** Ofwat's bad debt models exclude some important explanatory variables that demonstrably drive efficient costs. Specifically, variables capturing deprivation measures (for example, the Index of Multiple Deprivation (IMD) published by the ONS), are generally missing from Ofwat's bad debt models. Instead, Ofwat's models primarily use the Equifax 'default rate'. Whilst the combination of default rate and default amount will predict bad debt costs, the default rate is the outcome of a number of underlying factors – *some of which are within management control,* such as social tariff strategy. Accordingly, there are concerns that the current choice of variables does not capture the underlying characteristics of the customer base that influence the propensity to default. We also note that population transience is not included in Ofwat's models, whereas in its main consultation document, Ofwat's acknowledges it as a valid driver "*High transience can result in reduced ability to recover unpaid bills*"[8].

- **Non-bad debt models.** Similar to bad debt models, key cost drivers are omitted from some non-bad debt models. Examples of these variables include meter penetration and meter density. In addition, the use of dummy variables in individual years is questionable. That is, the interpretation of coefficients on these variables is ambiguous, as all they do, in principle, is identify whether costs have risen or fallen. They do not, however, identify *why* costs change - which can be due, for example, to inflation factors or productivity / frontier shift.

- **Total operating costs models.** Consistent with the above, we note that Ofwat's total retail operating costs include few explanatory variables.

Two overarching observations include the following:

- More generally, by expressing the dependent variable on a unit cost basis, Ofwat is effectively imposing an 'ACTS approach', rather than allowing the data to reveal scale and scope effects.

- Overall, a distinctive feature of Ofwat's models is that they are parsimonious, and while we do not have visibility of Ofwat's model selection process, it seems that the regulator has placed most weight on statistical significance. Specifically, if clustered standard errors were used as the basis for ruling variables in or out, then that would tend to reduce the number of explanatory variables found to be significant. This observation is consistent with comments made by Dr Anthony and Karli Glass in their response to Ofwat's consultation. Drs Glass note that: *"some potentially important explanatory variables may have been omitted"* and specifically recommend a model selection process where the standard errors are not clustered.[9]

[8] *Cost Assessment for PR19 – a consultation on econometric cost modelling.' Ofwat (May 2018); page 25.*

[9] *'Comments on 'Cost assessment for PR19: a consultation on econometric cost modelling.' Dr Anthony Glass and Dr Karli Glass; Loughborough University (2018).*

5. Efficiency Implications

This final chapter sets out the efficiency implications of the models presented in the preceding sections of our report. We first briefly discuss how econometric models are converted into efficiency gap estimates, before presenting the efficiency gaps implied by the econometric models.

5.1 Calculating efficiency gaps

In econometric cost models, efficiency scores are calculated using model residuals. Within the model residuals, however, inefficiency is not a distinct component. Residuals themselves also include random noise, and errors in the regression specification, alongside inefficiency. This leads to two practical issues in the use of econometric cost models to estimate efficiency gaps:

THE EFFICIENCY FRONTIER CANNOT BE PERFECTLY IDENTIFIED, AND IT IS UNCERTAIN HOW MUCH, AND HOW QUICKLY, EFFICIENCY GAPS CAN BE CLOSED.

- The efficiency frontier cannot be perfectly identified, and residuals cannot be assumed to consist wholly of inefficiency.
- It is uncertain as to "how much" of any efficiency gap can be closed, and "how quickly" this can be done.

A range of policy tools are available to regulators to address these issues, as we summarise in the table overleaf. Overall, the most important consideration in choosing between these options is that the eventual package of tools makes sense 'in the round'; and is considered within the context of actual model results.

Table 26: Key issues and relevant policy tools

Issue	Parameter	Policy tools
Frontier is not observable, so only a proportion of residuals represent inefficiency	Residuals adjustment	Percentage residual adjustments; statistical approaches (e.g. stochastic frontier).
	Frontier Selection	Upper quartile, upper quintile or average performance benchmark; pragmatic turnover rules; outlier treatment.
Uncertainty over how much and how quickly efficiency gap can be closed	Feasibility adjustment	Percentage adjustments to total efficiency gap.
	Glide path	Divide estimated gap by number of years in control.

Source: Economic Insight

The rest of this chapter presents the efficiency gap estimates across Economic Insight, Ofwat and Oxera models. For Economic Insight and Ofwat models, we calculate efficiency gap estimates to upper quartile as well as upper quintile. Benchmarking to upper quartile and quintile is consistent with Ofwat's policy position for a 'more aggressive' benchmarking than the average allowed for at PR14. For Oxera's models, we present efficiency scores to upper quartile only, as calculated by Oxera.

Our approach was such that we calculate the efficiency gap for Yorkshire across each of the total operating costs, bad debt and non-bad debt cost models respectively. Yorkshire should then choose the models and weights consistent with the wider objectives of its Business Plan.

5.2 Triangulation

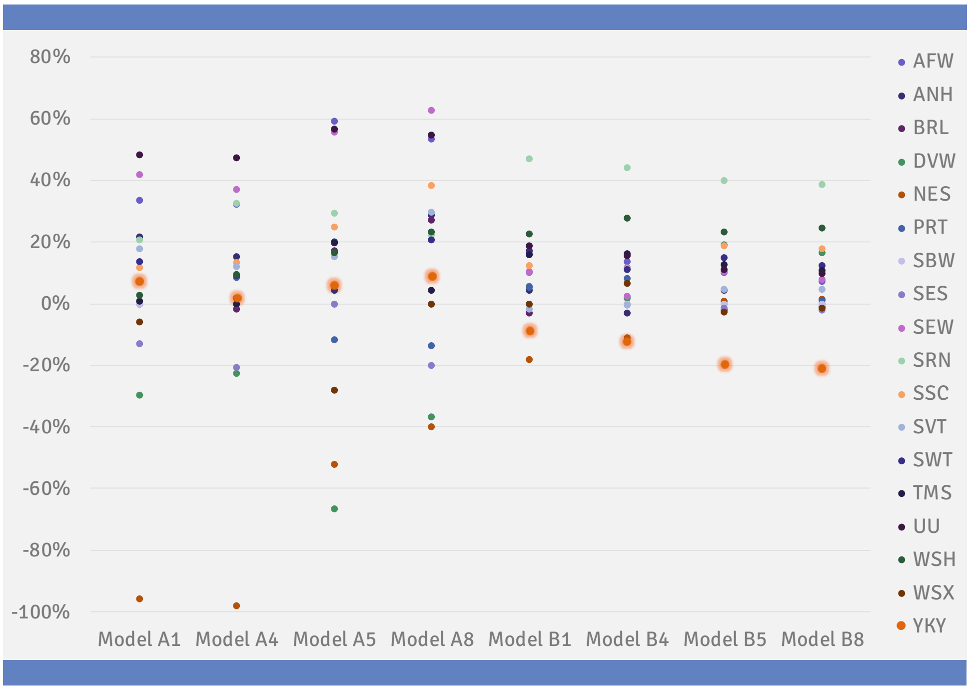
In this section we present model-level efficiency results from: i) Economic Insight; ii) Oxera; and iii) Ofwat.

5.2.1 Economic Insight models

The chart below shows all companies' implied efficiency gaps to upper quartile in Economic Insight's total retail cost models. The accompanying table summarises Yorkshire's position across these models.

5.2.1.1 Efficiency gap to upper quartile

Figure 3: Efficiency gap estimates to upper quartile - total operating costs models



Source: Economic Insight analysis

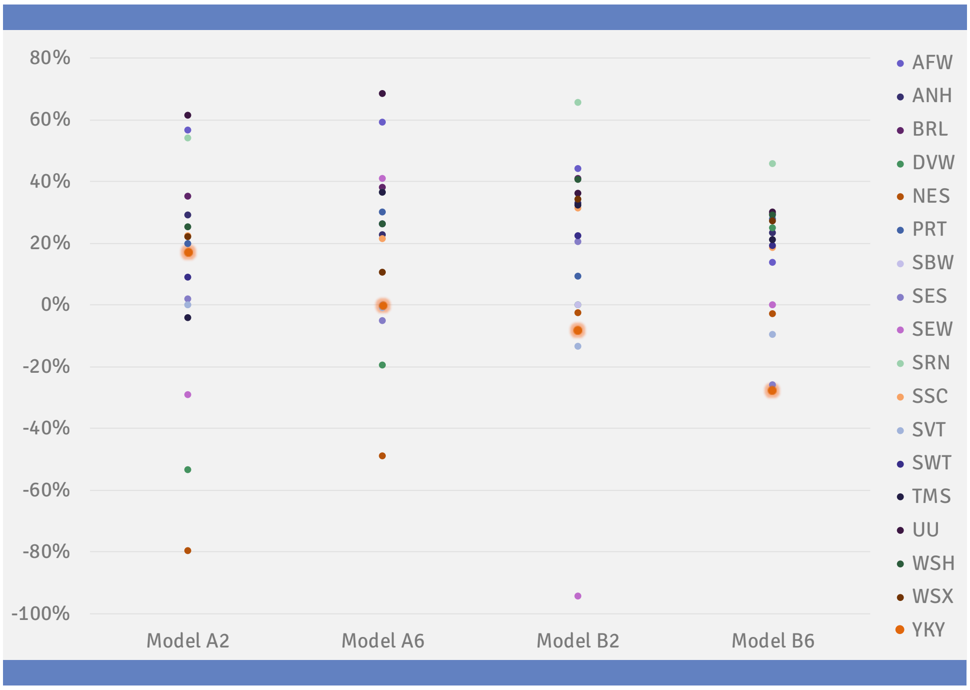
Table 27: Summary of Yorkshire's performance on Economic Insight's total operating costs models – upper quartile

Model	Model A1	Model A4	Model A5	Model A8	Model B1	Model B4	Model B5	Model B8
Yorkshire's efficiency score	7.3%	1.9%	6.2%	9.0%	-8.8%	-12.1%	-19.4%	-20.9%
Yorkshire's efficiency rank (1 = most efficient)[10]	9	7	7	7	2	1	1	1
Efficiency gap range	48.5% to -95.9%	47.2% to -98.1%	59.3% to -66.7%	62.7% to -40.0%	47.0% to -18.2%	44.3% to -12.1%	40.0% to -19.4%	38.6% to -20.9%

Source: Economic Insight analysis

Figure 4 below shows all companies' implied efficiency gaps to upper quartile in Economic Insight's bad debt cost models. The accompanying table summarises Yorkshire's efficiency score and rank across these models.

Figure 4: Efficiency gap estimates to upper quartile - bad debt cost models



Source: Economic Insight analysis

[10] *Note that the total number of firms is 17.*

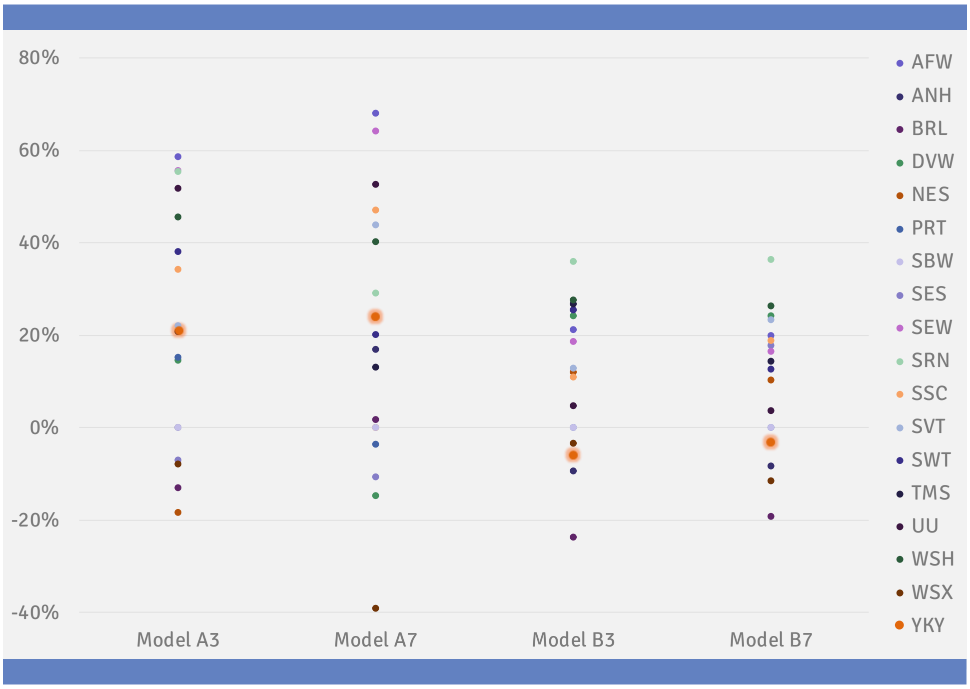
Table 28: Summary of Yorkshire's performance on Economic Insight's bad debt cost models – upper quartile

Model	Model A2	Model A6	Model B2	Model B6
Yorkshire's efficiency score	17.3%	0.0%	-8.2%	-27.5%
Yorkshire's efficiency rank (1 = most efficient)	8	5	3	1
Efficiency gap range	61.4% to -79.7%	68.6% to -49.0%	65.6% to -94.4%	45.9% to -27.5%

Source: Economic Insight analysis

The following figure shows all companies' implied efficiency gaps to upper quartile in Economic Insight's non-bad debt cost models. The accompanying table summarises Yorkshire's efficiency score and rank across these models.

Figure 5: Efficiency gap estimates to upper quartile - non-bad debt cost models



Source: Economic Insight analysis

Table 29: Summary of Yorkshire's performance on Economic Insight's non-bad debt cost models – upper quartile

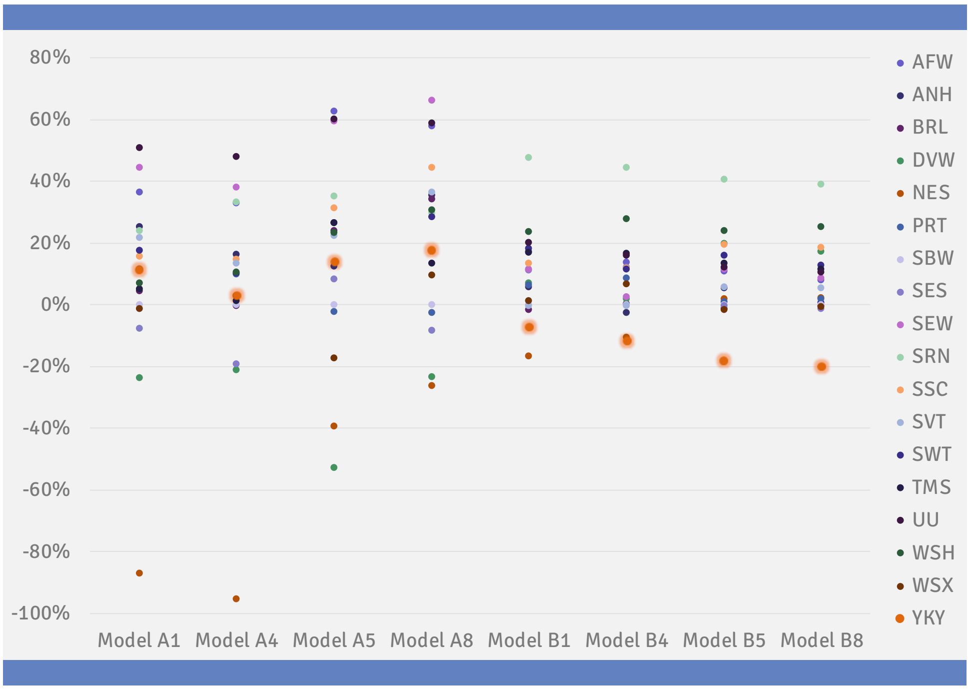
Model	Model A3	Model A7	Model B3	Model B7
Yorkshire's efficiency score	21.2%	24.2%	-5.8%	-3.1%
Yorkshire's efficiency rank (1 = most efficient)	9	10	3	4
Efficiency gap range	58.7% to -18.4%	68.1% to -39.0%	35.9% to -23.5%	36.4% to -19.1%

Source: Economic Insight analysis

5.2.1.2 Efficiency gap to upper quintile

As discussed, efficiency gap to upper quintile presents a more challenging threshold for companies. The chart below shows the implied efficiency gap to upper quintile for all companies in Economic Insight's total retail cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 6: Efficiency gap estimates to upper quintile - total operating costs models



Source: Economic Insight analysis

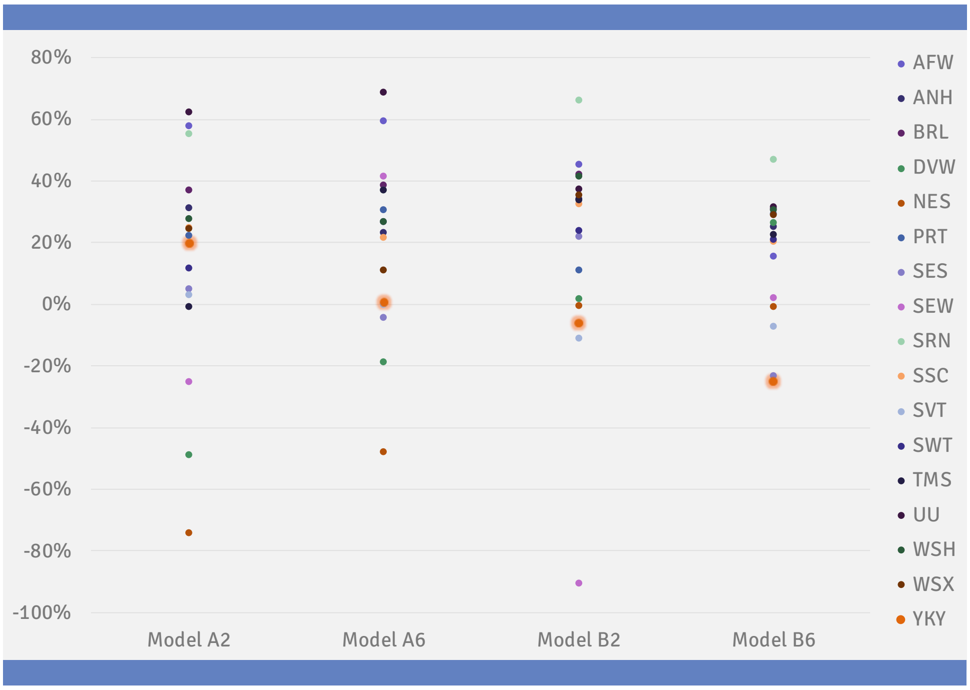
Table 30: Summary of Yorkshire's performance on Economic Insight's total operating costs models – upper quintile

Model	Model A1	Model A4	Model A5	Model A8	Model B1	Model B4	Model B5	Model B8
Yorkshire's efficiency score	11.5%	3.3%	14.1%	17.9%	-7.3%	-11.6%	-18.2%	-19.9%
Yorkshire's efficiency rank (1 = most efficient)	9	7	7	7	2	1	1	1
Efficiency gap range	50.8% to -87.0%	47.9% to -95.5%	62.7% to -52.6%	66.3% to -26.3%	47.7% to -16.6%	44.5% to -11.6%	40.6% to -18.2%	39.1% to -19.9%

Source: Economic Insight analysis

The following chart shows the implied efficiency gap to upper quintile for all companies in Economic Insight's bad debt cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 7: Efficiency gap estimates to upper quintile - bad debt models



Source: Economic Insight analysis

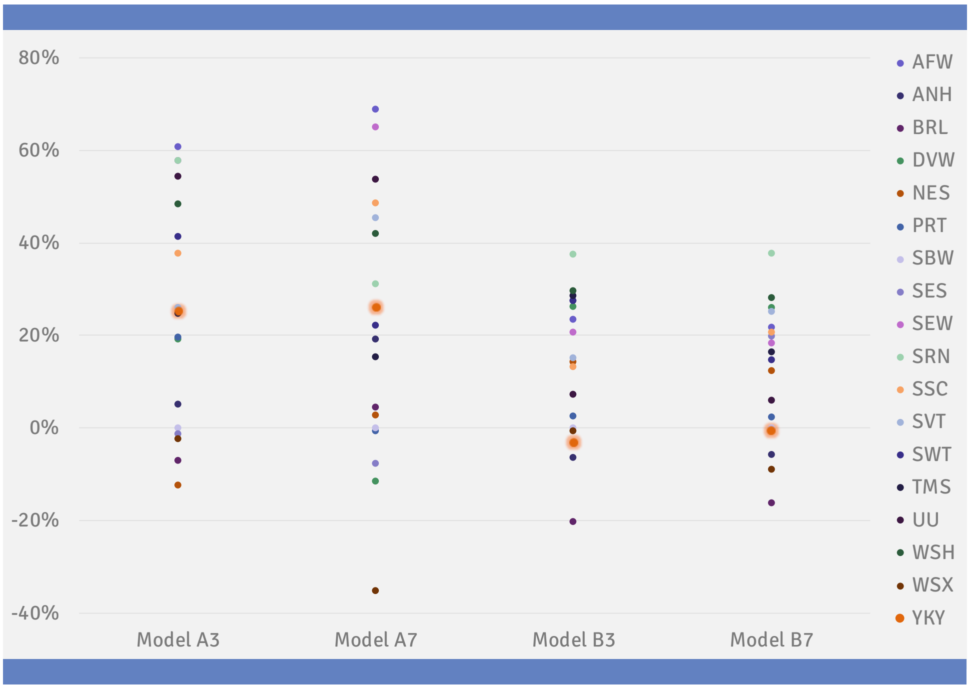
Table 31: Summary of Yorkshire's performance on Economic Insight's bad debt models – upper quintile

Model	Model A2	Model A6	Model B2	Model B6
Yorkshire's efficiency score	19.8%	0.7%	-6.0%	-24.8%
Yorkshire's efficiency rank (1 = most efficient)	8	5	3	1
Efficiency gap range	62.6% to -74.1%	68.8% to -48.0%	66.2% to -90.6%	47.0% to -24.8%

Source: Economic Insight analysis

Figure 8 below shows the implied efficiency gap to upper quintile for all companies in Economic Insight's non-bad debt cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 8: Efficiency gap estimates to upper quintile - non-bad debt cost models



Source: Economic Insight analysis

Table 32: Summary of Yorkshire's performance on Economic Insight's non-bad debt cost models – upper quintile

Model	Model A3	Model A7	Model B3	Model B7
Yorkshire's efficiency score	25.3%	26.2%	-3.0%	-0.6%
Yorkshire's efficiency rank (1 = most efficient)	9	10	3	4
Efficiency gap range	60.8% to -12.3%	68.9% to -35.3%	37.6% to -20.3%	37.9% to -16.3%

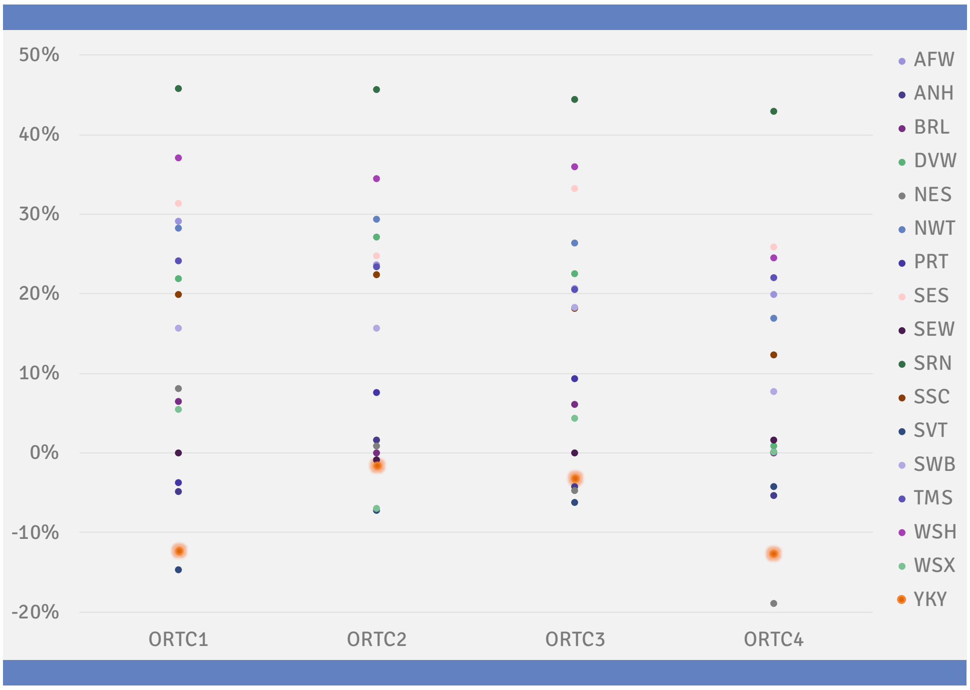
Source: Economic Insight analysis

5.2.2 Ofwat models

5.2.2.1 Efficiency gap to upper quartile

The chart below shows all companies' implied efficiency gaps to upper quartile in Ofwat's total retail cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 9: Efficiency gap to upper quartile - total operating costs models



Source: Ofwat

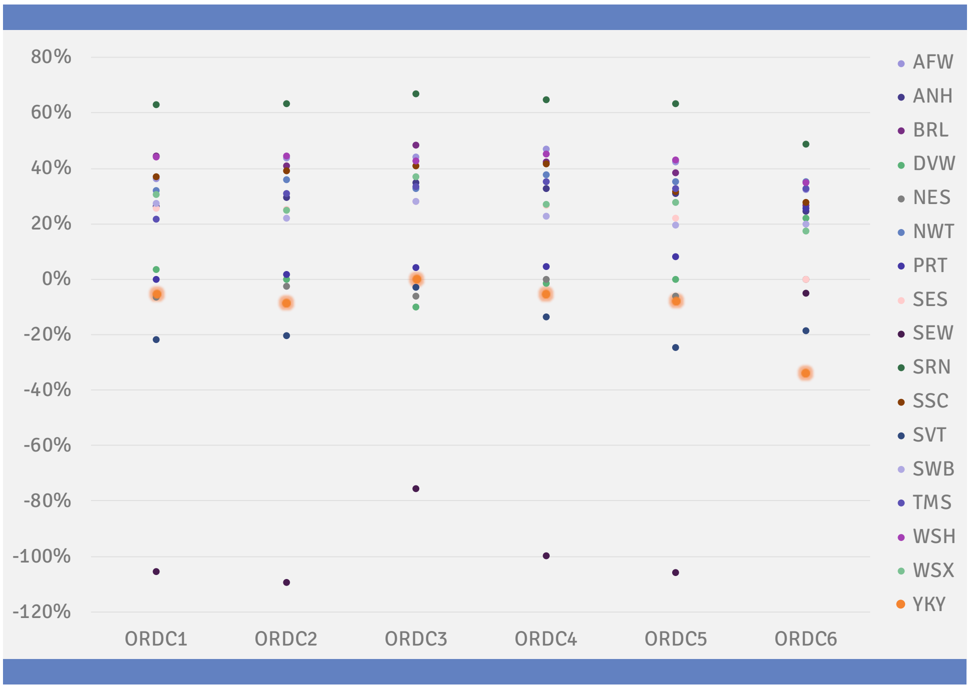
Table 33: Summary of Yorkshire's performance on Ofwat's total operating costs models – upper quartile

Model	ORTC1	ORTC2	ORTC3	ORTC4
Yorkshire's efficiency score	-12.2%	-1.6%	-3.3%	-12.6%
Yorkshire's efficiency rank (1 = most efficient)	2	3	4	2
Efficiency gap range	45.7% to -14.8%	45.7% to -7.3%	44.4% to -6.2%	42.9% to -18.9%

Source: Economic Insight analysis of Ofwat's retail models

The chart below shows all companies' implied efficiency gaps to upper quartile in Ofwat's total retail cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 10: Efficiency gap to upper quartile - bad debt cost models



Source: Ofwat

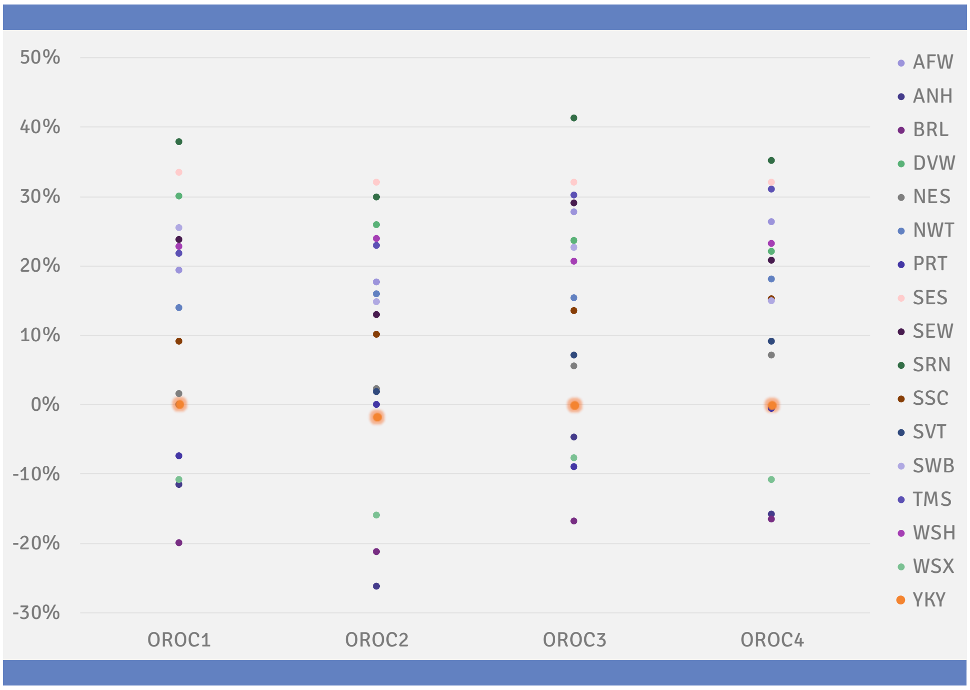
Table 34: Summary of Yorkshire's performance on Ofwat's bad debt cost models – upper quartile

Model	ORDC1	ORDC2	ORDC3	ORDC4	ORDC5	ORDC6
Yorkshire's efficiency score	-5.2%	-8.3%	0.0%	-5.3%	-7.7%	-33.7%
Yorkshire's efficiency rank (1 = most efficient)	4	3	5	3	3	1
Efficiency gap range	63.% to -105.4%	63.3% to -109.4%	67.0% to -75.6%	64.8% to -99.9 %	63.3% to -106.0%	48.7% to -33.7%

Source: Economic Insight analysis of Ofwat's retail models

The following chart shows all companies' implied efficiency gaps to upper quartile in Ofwat's bad debt cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 11: Efficiency gap to upper quartile - total operating costs less bad debt cost models



Source: Ofwat

Table 35: Summary of Yorkshire's performance on Ofwat's non-bad debt models – upper quartile

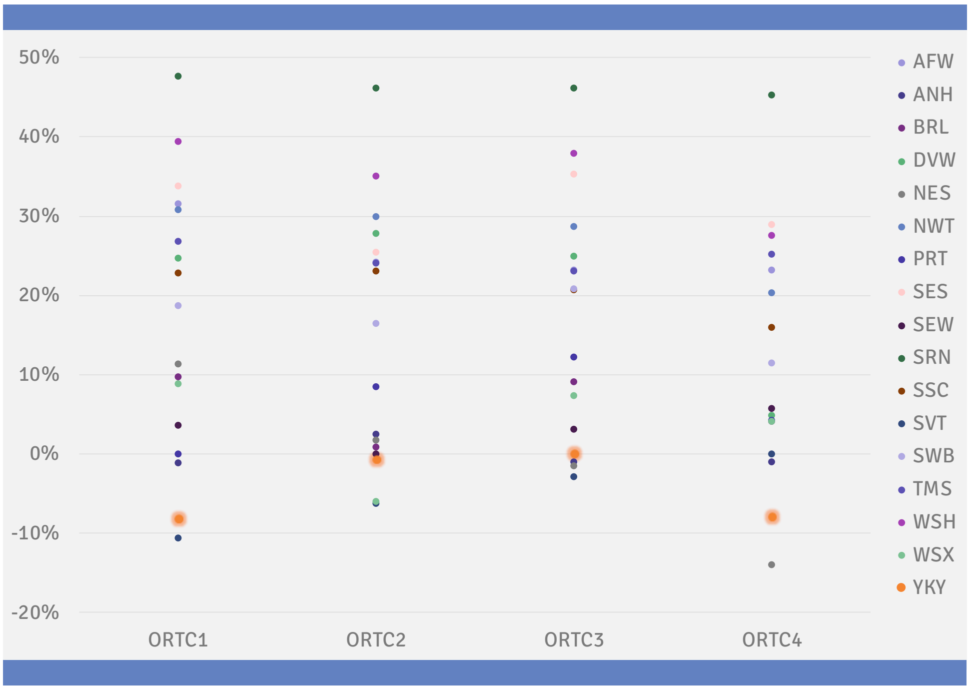
Model	OROC1	OROC2	OROC3	OROC4
Yorkshire's efficiency score	0.0%	-1.8%	0.0%	0.0%
Yorkshire's efficiency rank (1 = most efficient)	6	4	5	5
Efficiency gap range	37.9% to -20.0%	32.1% to -26.2%	41.3% to -16.9%	35.3% to -16.4%

Source: Economic Insight analysis of Ofwat's retail models

5.2.2.2 Efficiency gap to upper quintile

The chart below shows all companies' implied efficiency gaps to upper quintile in Ofwat's total retail cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 12: Efficiency gap to upper quintile - total operating costs models



Source: Ofwat

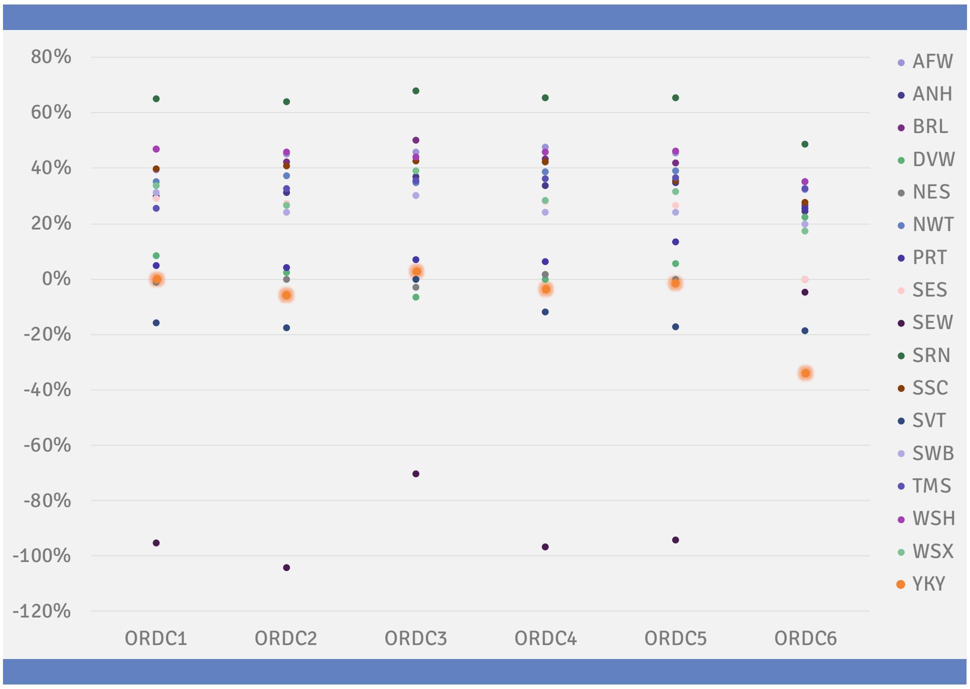
Table 36: Summary of Yorkshire's performance on Ofwat's total operating costs models - upper quintile

Model	ORTC1	ORTC2	ORTC3	ORTC4
Yorkshire's efficiency score	-8.2%	-0.7%	0.0%	-8.0%
Yorkshire's efficiency rank (1 = most efficient)	2	3	4	2
Efficiency gap range	47.7% to -10.6%	46.1% to -6.3%	46.2% to -2.9%	45.3% to -14.0%

Source: Economic Insight analysis of Ofwat's retail models

Figure 13 below shows all companies' implied efficiency gaps to upper quintile in Ofwat's bad debt cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 13: Efficiency gap to upper quintile – bad debt cost models



Source: Ofwat

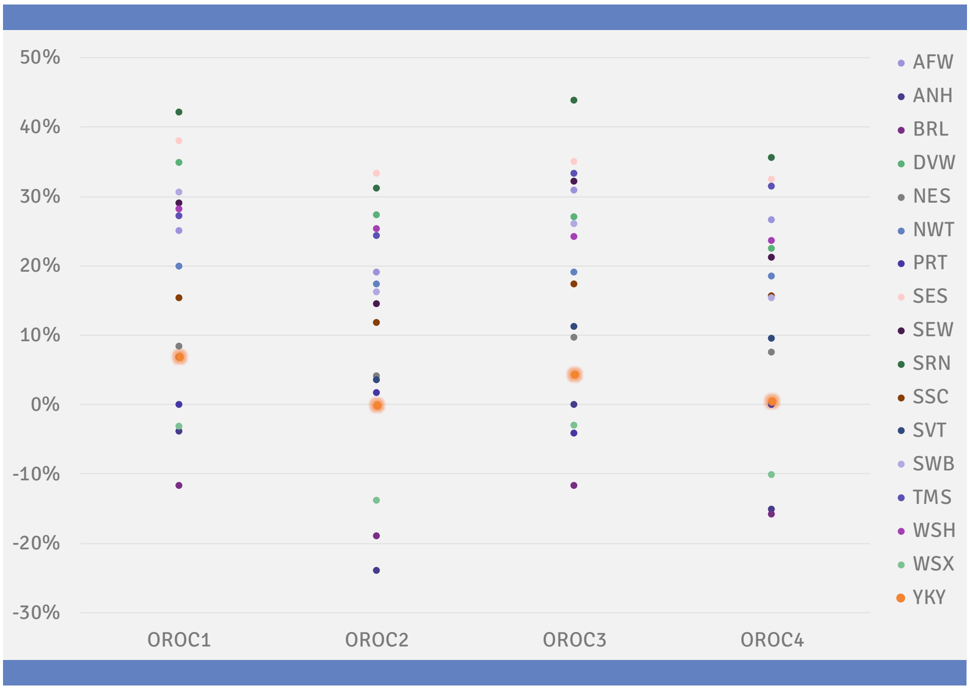
Table 37: Summary of Yorkshire's performance on Ofwat's bad debt cost models - upper quintile

Model	ORDC1	ORDC2	ORDC3	ORDC4	ORDC5	ORDC6
Yorkshire's efficiency score	0.0%	-5.6%	2.9%	-3.7%	-1.5%	-33.7%
Yorkshire's efficiency rank (1 = most efficient)	4	3	5	3	3	1
Efficiency gap range	65.0% to -95.3%	64.2% to -104.3%	68.0% to -70.5%	65.3% to -96.7%	65.4% to -94.3%	48.7% to -33.7%

Source: Economic Insight analysis of Ofwat's retail models

The chart below shows all companies' implied efficiency gaps to upper quintile in Ofwat's non-bad debt cost models. The accompanying table summarises Yorkshire's position across these models.

Figure 14: Efficiency gap to upper quintile – total operating costs less bad debt cost models



Source: Ofwat

Table 38: Summary of Yorkshire's performance on Ofwat's non-bad debt cost models - upper quintile

Model	OROC1	OROC2	OROC3	OROC4
Yorkshire's efficiency score	6.9%	0.0%	4.4%	0.5%
Yorkshire's efficiency rank (1 = most efficient)	6	4	5	5
Efficiency gap range	42.2% to -11.7%	33.3% to -24.0%	43.9% to -11.7%	35.6% to -15.8%

Source: Economic Insight analysis of Ofwat's retail models

5.2.3 Oxera models

The following tables summarise Yorkshire's position across Oxera's main botex, bad debt and non-bad debt models, consequently.

Table 39: Summary of Yorkshire's performance on Oxera's main botex models

Model	BOTEX1	BOTEX2	BOTEX3	BOTEX4
Yorkshire's efficiency score	-12.9%	-6.9%	-9.3%	-10.1%
Yorkshire's efficiency rank (1 = most efficient)	3	2	3	2
Efficiency gap range	42.9% to -17.1%	45.9% to -11.1%	41.3% to -13.7%	43.1% to -15.9%

Source: Oxera

Table 40: Summary of Yorkshire's performance on Oxera's main bad debt models

Model	Bad debt 1	Bad debt 2	Bad debt 3	Bad debt 4
Yorkshire's efficiency score	-37.5%	-33.3%	-27.4%	-40.5%
Yorkshire's efficiency rank (1 = most efficient)	1	1	2	1
Efficiency gap range	51.8% to -37.2%	107.6% to -33.4%	63.0% to -30.0%	45.5% to -40.5%

Source: Oxera

Table 41: Summary of Yorkshire's performance on Oxera's main non-bad debt models

Model	Non-bad debt 1	Non-bad debt 2	Non-bad debt 3	Non-bad debt 4
Yorkshire's efficiency score	12.0%	1.7%	14.1%	10.3%
Yorkshire's efficiency rank (1 = most efficient)	6	5	7	8
Efficiency gap range	55.8% to -18.2%	44.6% to -32.4%	52.8% to -21.2%	28.7% to -28.3%

Source: Oxera

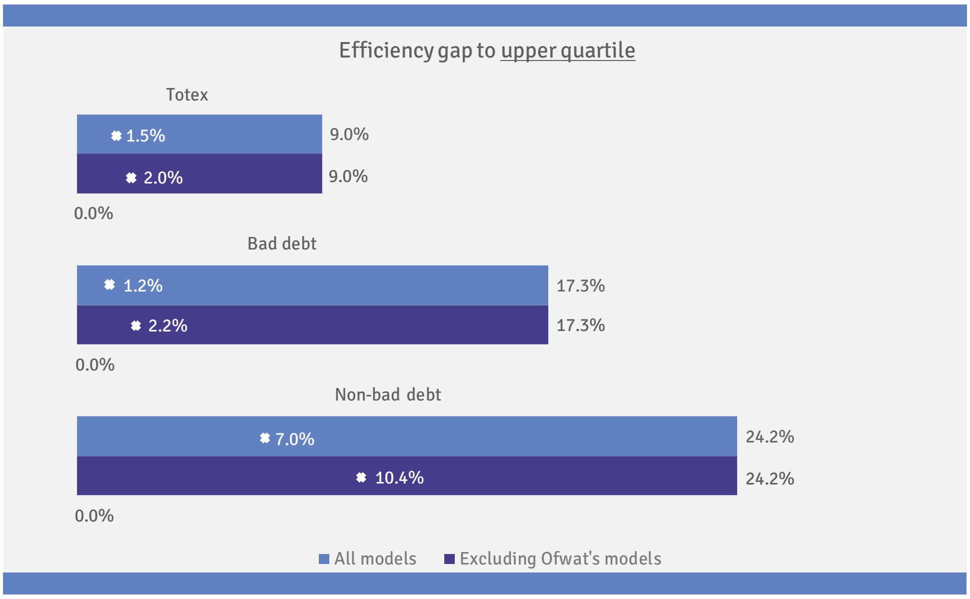
5.3 Overall range for Yorkshire

In this final section, we summarise Yorkshire's efficiency gap estimates to upper quartile and upper quintile across: total operating costs, bad debt, and non-bad debt models.

5.3.1 Upper quartile efficiency gap

Overall, we find that Yorkshire's efficiency gap estimates to **upper quartile** are in the range of 0%[11] to 9.0% across total operating costs models; 0% to 17.3% across bad debt models; and 0% to 24.2% across non-bad debt cost models. Taken together, the bad debt and non-bad debt models imply a range of 0% to 21.3%.

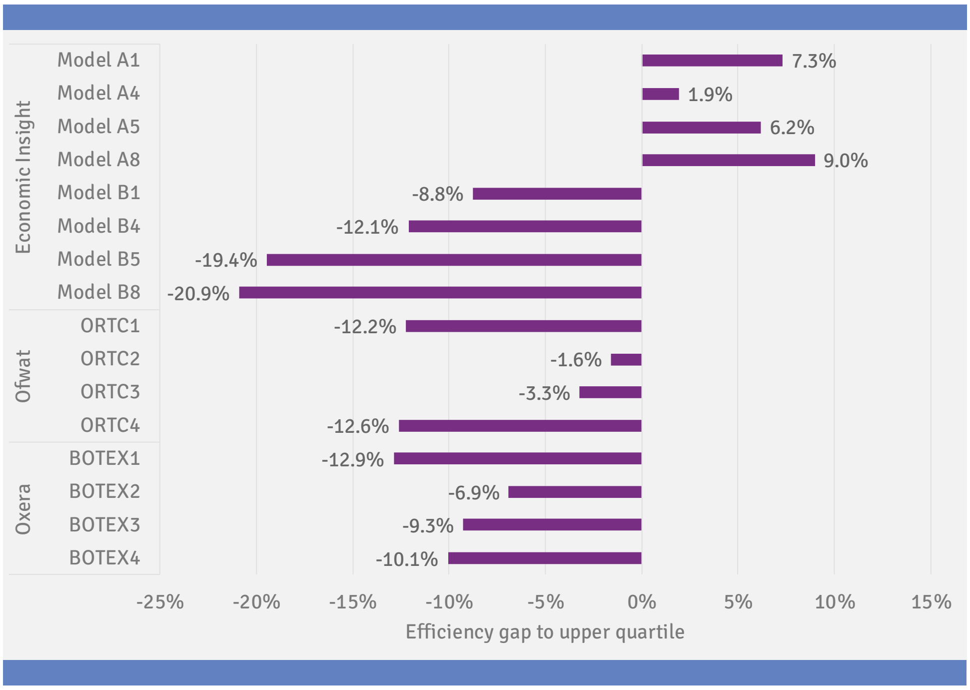
Figure 15: Range of efficiency gap estimates to upper quartile



Source: Economic Insight analysis

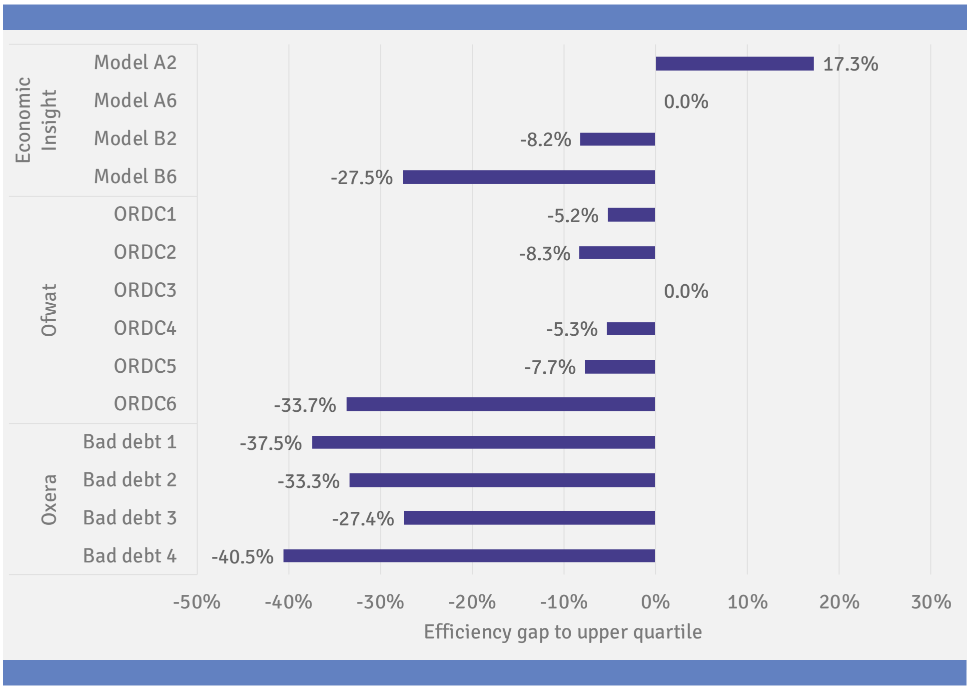
[11] A negative efficiency gap is when Yorkshire performs better than the benchmark.

Figure 16: Efficiency gap to upper quartile, total operating costs models



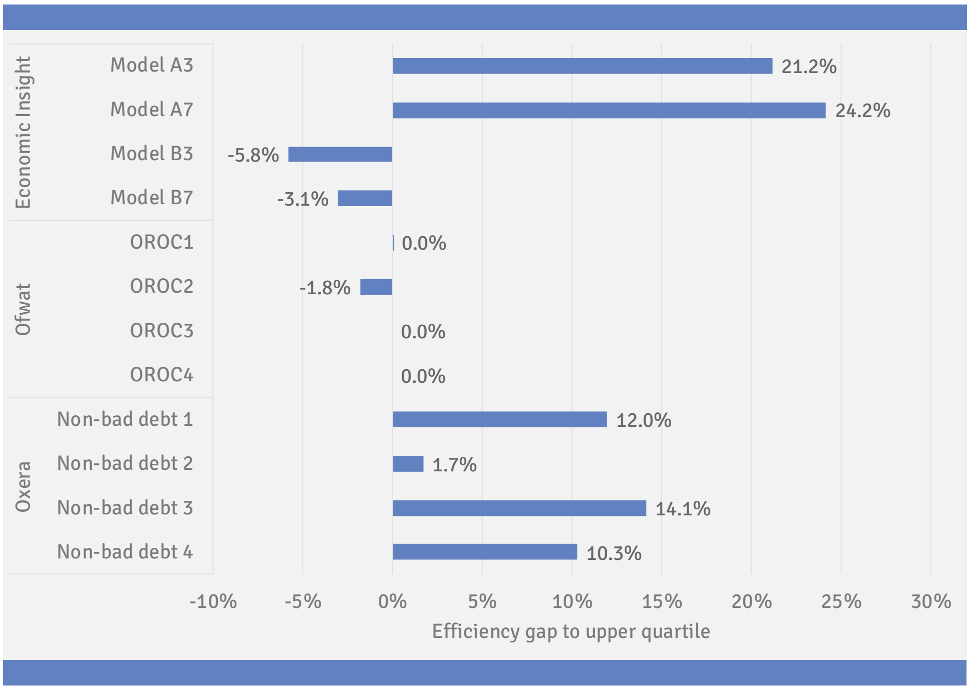
Source: Economic Insight, Ofwat and Oxera

Figure 17: Efficiency gap estimates to upper quartile, bad debt cost models



Source: Economic Insight, Ofwat and Oxera

Figure 18: Efficiency gap estimates to upper quartile, non-bad debt cost models

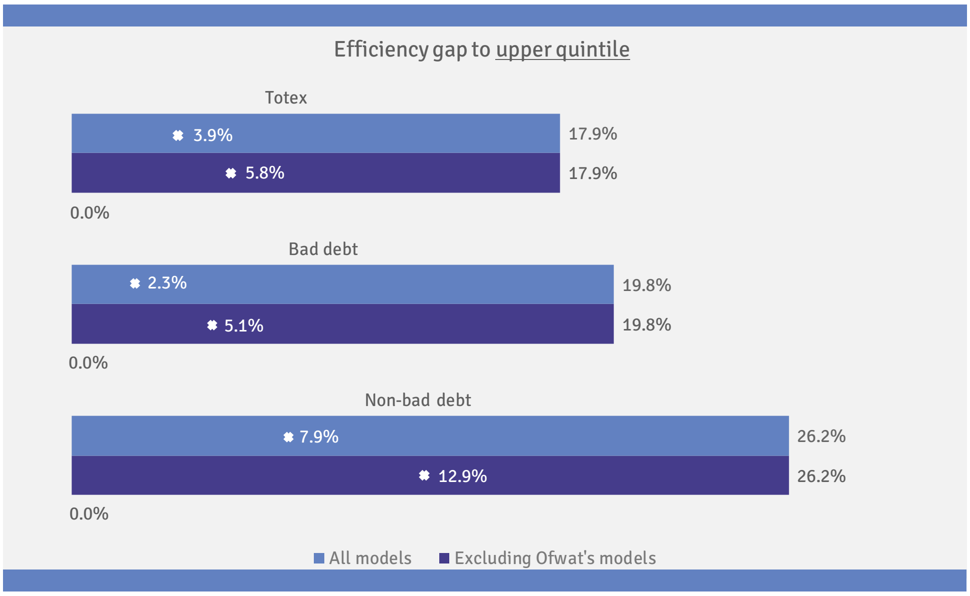


Source: Economic Insight, Ofwat

5.3.2 Upper quintile efficiency gap

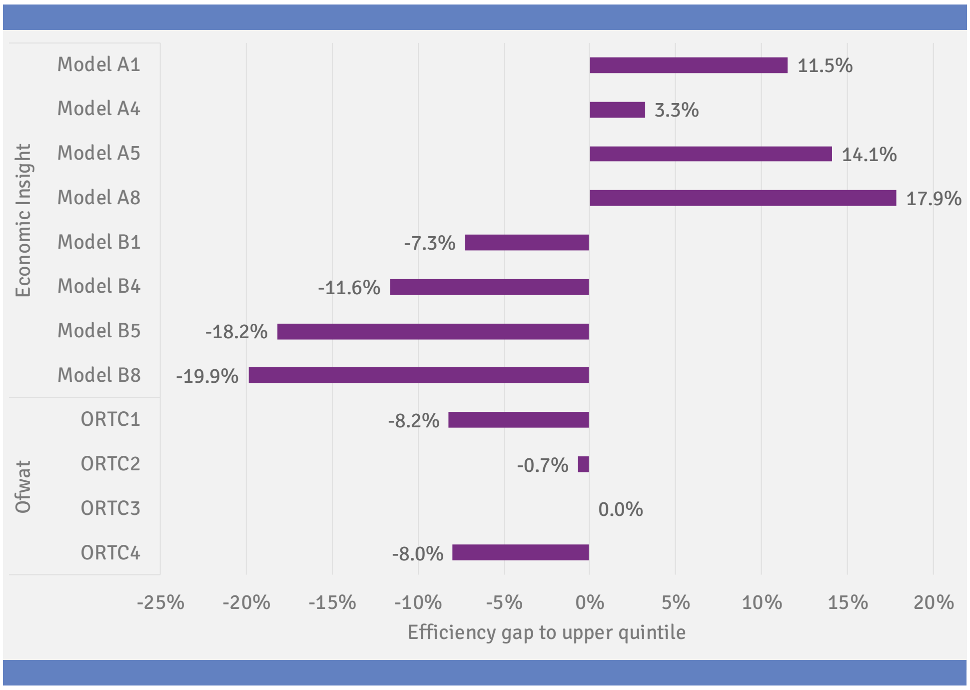
Yorkshire's efficiency gap estimates to the more challenging **upper quintile** benchmark are in the range of 0% to 17.9% across total operating costs models; 0% to 19.8% across bad debt models; and 0% to 26.2% across non-bad debt cost models. Taken together, the bad debt and non-bad debt models imply a range of 0% to 23.6%.

Figure 19: Range of efficiency gap estimates to upper quintile



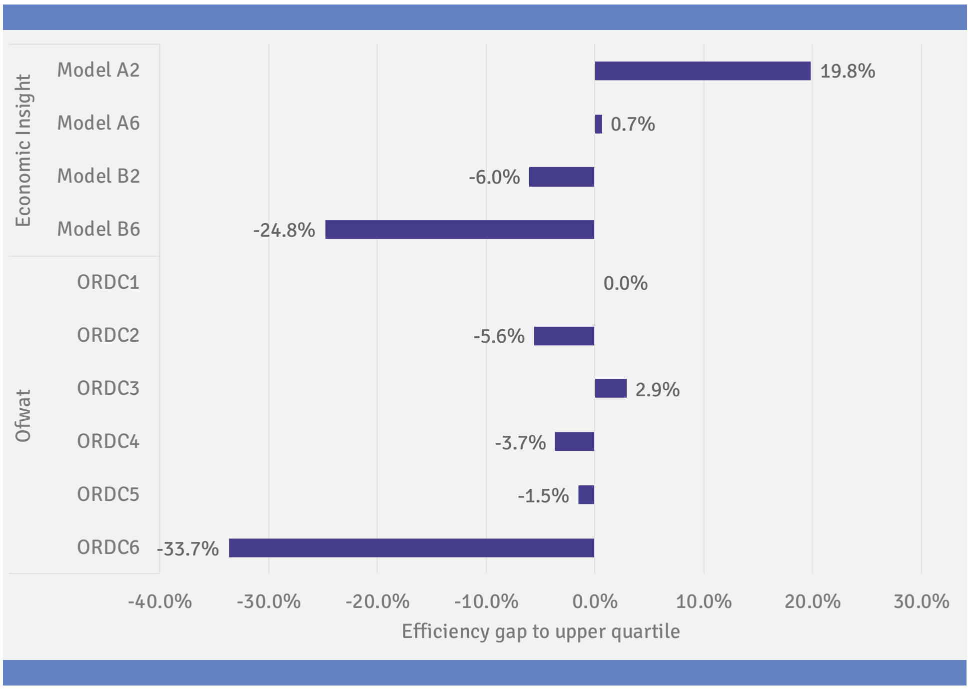
Source: Economic Insight analysis

Figure 20: Efficiency gap estimates to upper quintile, total operating costs models



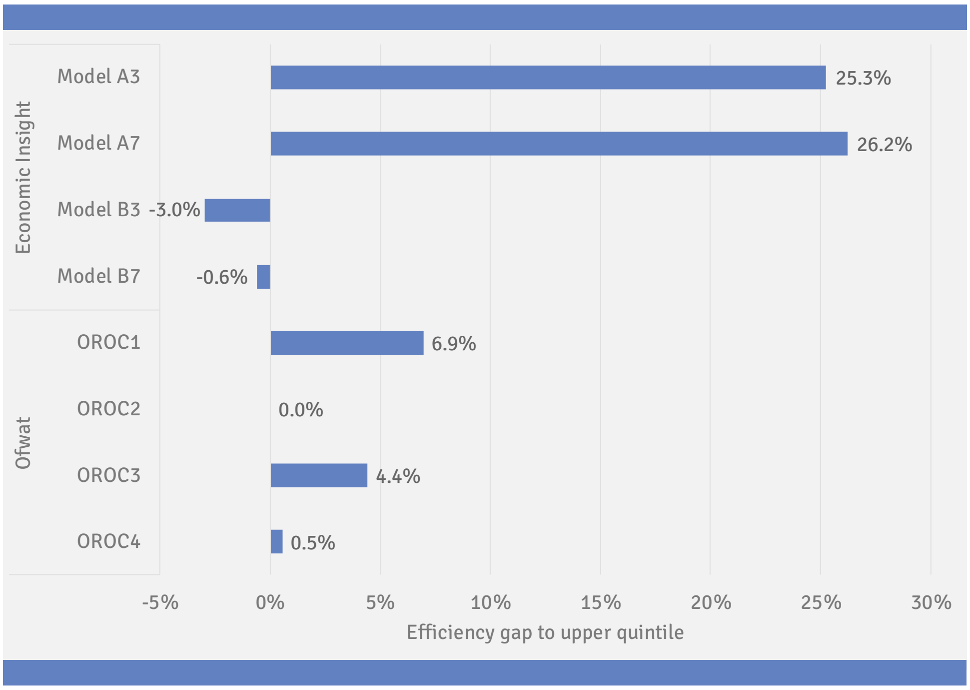
Source: Economic Insight, Ofwat and Oxera

Figure 21: Efficiency gap estimates to upper quintile, bad debt cost models



Source: Economic Insight, Ofwat and Oxera

Figure 22: Efficiency gap estimates to upper quintile, non-bad debt cost models



Source: Economic Insight, Ofwat and Oxera

WE MAKE ECONOMICS RELEVANT

Economic Insight Limited

125 Old Broad Street
London
EC2N 1AR
0207 100 3746
www.economic-insight.com

YORKSHIREWATER.COM

Yorkshire Water Services Limited, Western House, Halifax Road,
Bradford, BD6 2SZ. Registered in England and Wales No.2366682