NERA
ECONOMIC CONSULTING

Privileged and Confidential

Comparative Benchmarking Assessment to Support Preparation of Bristol Water's AMP7 Business Plan

Prepared for Bristol Water

20 December 2017

Project Team

Richard Druce
Ambrus Barany
Sam Jindani
Adriana Linares
Edward Mills

NERA Economic Consulting
Marble Arch House, 66 Seymour Street
London W1H 5BT
United Kingdom
Tel: 44 20 7659 8500 Fax: 44 20 7659 8501
www.nera.com

CONFIDENTIALITY

We understand that the maintenance of confidentiality with respect to our clients' plans and data is critical to their interests. NERA Economic Consulting rigorously applies internal confidentiality practices to protect the confidentiality of all client information.

Similarly, our approaches and insights are proprietary and so we look to our clients to protect our interests in our proposals, presentations, methodologies and analytical techniques. Under no circumstances should this material be shared with any third party without the prior written consent of NERA Economic Consulting.

Contents

Privileged and Confidential

Executive Summary

Our Remit and Scope of this Report

In preparation for the PR19 price control review, Bristol Water has commissioned NERA Economic Consulting (NERA) to conduct a comparative benchmarking exercise to inform the efficiency targets that should be built into its Business Plan submission to Ofwat. Additionally, recognising the limitations of comparative benchmarking models, Bristol Water has asked us to identify and quantify its special cost factors, ie. to identify inherent differences between Bristol Water and its comparators that may not be controlled for adequately by benchmarking models and to quantify the effects of these differences. This report focusses on re-running existing benchmarking models and developing new benchmarking models to assess Bristol Water's economic efficiency. We discuss our analysis of Bristol Water's special cost factors in our separate special cost factors report.

Update of Existing Models

We started our benchmarking analysis by updating three sets of econometric benchmarking models developed previously within the industry price reviews: (1) Ofwat's models developed for the PR14 price control; (2) the CMA's models developed for the Bristol Water referral at PR14; and (3) Oxera's recent models developed for a group of water companies in preparation for the PR19 review:

- Ofwat's models suggest that Bristol Water is one of the least efficient water companies in England and Wales. Specifically, we estimate an efficiency gap of about 30% for Bristol Water for both base expenditure (botex) and total expenditure (totex), suggesting that Bristol Water's actual costs were 30% higher than its upper quartile efficient costs over the 2012-2017 period. However, we conclude that Ofwat's PR14 models are not fit for use at PR19, because there are several economic and technical econometric issues with these models, including those identified by the CMA during the Bristol Water referral.
- The CMA's models, updated using the latest data from Ofwat, produce similar results for Bristol Water as Ofwat's PR14 models, ie. large efficiency gaps for Bristol Water. However, as with the Ofwat PR14 models, we have identified serious statistical robustness problems with the CMA's models. Further, the CMA itself recommended improvements to its modelling, which it could not implement during the Bristol Water referral due to time and data constraints. Therefore, we conclude that the CMA's models would not have met the CMA's own model selection criteria when estimated using the latest industry data. We therefore conclude that, like the Ofwat PR14 models, they are not fit for use at PR19.
- Oxera developed a number of models for total base expenditure ("aggregate botex"), water resources botex, and "network plus" ("network+") botex, which consists of raw water transport, water treatment and water distribution. Oxera's models also suggest that Bristol Water is one of the least efficient water companies in England and Wales. In water resources, we estimate an efficiency gap for Bristol Water of over 100% (implying that Bristol Water's actual costs were more than double its efficient costs). The estimated efficiency gap in the aggregate botex and network+ models ranges from 15% to 44%, depending on the exact model used. However, we have identified a range of statistical problems with Oxera's models, most likely due to omitted variables, and some models

Privileged and Confidential

exhibit counterintuitive coefficients. Given these robustness problems with Oxera's models, we consider they would also need to be developed further before they could be applied at PR19.

Our Model Development for Bristol Water

Given these limitations of existing models, we have developed our own, more statistically robust benchmarking models for Bristol Water based on a rigorous model development process:

1. We first made a number of high level methodological choices for developing our models, following regulatory precedent, the CMA's recommendations, and economic intuition;
2. We then identified a long list of candidate cost drivers for inclusion in our models;
3. We used a Monte Carlo tool to help us identify a short list of the most important cost drivers that lead to the most robust models for the industry as a whole; and
4. We developed our final models by selecting drivers to include from the short list of cost drivers identified using our Monte Carlo tool, based on expert judgement.

Our final models are all more statistically robust than the Ofwat, CMA and Oxera models: they pass key econometric tests for model specification, have a high explanatory power, and the majority of cost drivers included in these models have a statistically significant impact on costs. Further, all coefficients in the final models have an economically intuitive size and sign.

While the primary purpose of our model development has been to create statistically robust models, we have also found that these models control for the cost drivers that are most relevant for Bristol Water. As a result, these models show Bristol Water to be more efficient than the Ofwat, CMA or Oxera models. In particular, our models control for Bristol Water's high levels of water treatment complexity.

Our models show an efficiency gap of approximately 13% for Bristol Water over the 2014-2017 period. For the latest year (2016/17), we find that Bristol Water is very close to upper quartile efficiency, with an efficiency gap of below 1%. The reason for its declining efficiency gap over time is the trend reduction in capital maintenance expenditure over the 2014-17 period.

Privileged and Confidential

1. Introduction

Over the next two years, Ofwat will set the "PR19" price control for the English and Welsh Water only Companies (WOCs) and Water and Sewerage Companies (WaSCs) for the 5-year period from 1 April 2020, the Seventh Asset Management Plan Period (AMP7). As part of the price control review process, companies are required to submit their Business Plans to Ofwat by 3 September 2018, which forecast each individual company's activities and expenditures for AMP7.[1]

Against this background, Bristol Water has commissioned NERA Economic Consulting (NERA) to assess Bristol Water's current level of cost efficiency using comparative benchmarking. The purpose of our analysis is to inform Bristol Water on the efficiency targets that should be built into its Business Plan submissions to Ofwat.

This report discusses the methodology and results of this benchmarking analysis and our work to identify and quantify special cost factors. It is structured as follows:

- In Chapter 2, we describe the most relevant recent econometric benchmarking models developed at recent price reviews, covering the Ofwat's models from PR14, and the CMA's models developed for the Bristol Water referral. We also describe Oxera's models developed for a group of water companies in preparation for PR19.
- In Chapter 3, we present the results we obtain from updating these models using the latest industry cost and driver data;
- In Chapter 4, we discuss the models we have developed for Bristol Water and present the results; and
- Chapter 5 concludes.

1 Ofwat (July 2017), "*Delivering Water 2020: Consulting on our methodology for the 2019 price review*", p.22.

2. Comparative Benchmarking at Recent Water Price Control Reviews

In this chapter, we describe the benchmarking processes and methods followed at PR14 by Ofwat (in Section 2.1), as well as the CMA's views on Ofwat's benchmarking methods and the models it developed itself during the Bristol Water referral (in sections 2.2.1 and 2.2.2). Finally, in Section 2.3 we discuss the methodology and models Oxera has developed for a group of water companies in preparation for the PR19 price control.

2.1. Ofwat's PR14 Modelling

At PR14, as at previous reviews, Ofwat used comparative benchmarking techniques to assess the efficient costs of the English and Welsh Water only Companies (WoCs) and Water and Sewerage Companies (WaSCs).

Ofwat developed separate sets of econometric models for wholesale water and wholesale sewerage services.[2] The dataset used in these models is publicly available on Ofwat's website.[3] We provide a short summary of the main features of Ofwat's wholesale water services models below.

Ofwat developed three econometric models to assess companies' total expenditure (totex) and two models to assess companies' base expenditure (botex), which is defined as operating expenditure (opex), plus capital maintenance expenditure.[4] These five econometric models differed in two dimensions:

- **The statistical estimation method,** either pooled Ordinary Least Squares (OLS) or Random Effects (RE); [5]
- **The explanatory variables used**: Ofwat used an "un-refined" model, where it included all explanatory variables it considered to be relevant; and a "refined" model, where it excluded explanatory variables that it concluded were not statistically important or had a counterintuitive modelled effect on costs. We list the refined and un-refined sets of explanatory variables used by Ofwat in Table 2.1 below.

---

2 Ofwat (2014) *"Cost Assessment – Advanced Econometric Models"*. Final report submitted by CEPA.

3 Ofwat (2014) *"Basic Cost Threshold Feeder Model"*, Appendix A – Water/Wastewater Data Inputs. Available at http://webarchive.nationalarchives.gov.uk/20150624091829/https:/www.ofwat.gov.uk/pricereview/pr14/wholesale/prs_web140404pr14wholesalecostasses

4 In other words, botex is equal to totex *minus* enhancement expenditure, which is the most lumpy and company-specific area of costs.

5 Pooled OLS models are often called corrected OLS (or COLS) models when used for comparative benchmarking, as the models are typically "corrected" to target above-average efficiency.

Privileged and Confidential

Table 2.1
Explanatory Variables Used by Ofwat in PR14 – Wholesale Water Service

Description	Inclusion in "un-refined" model	Inclusion in "refined model"
Constant term	✓	✓
Ln (length of mains)	✓	✓
Ln (connected properties / length of mains)	✓	✓
Ln (potable water delivered / connected properties)	✓	
[Ln (length of mains)] ^ 2	✓	✓
[Ln (connected properties / length of mains] ^ 2	✓	✓
[Ln (potable water delivered / connected properties)] ^ 2	✓	
Ln (length of mains) * Ln (connected properties / length of mains)	✓	✓
Ln (length of mains) * Ln (potable water delivered / connected properties)	✓	
Ln (connected properties / length of mains) *Ln (potable water delivered / connected properties)	✓	
Ln (regional wage)	✓	✓
Ln (population supplied / connected properties)	✓	✓
Ln (proportion of properties that are metered)	✓	
Ln (total number of sources / total distribution input)	✓	
Ln (average pumping head * total distribution input)	✓	
Ln (proportion of distribution input from river abstractions)	✓	✓
Ln (proportion of distribution input from reservoirs)	✓	✓
Ln (number of new meters installed in year as a proportion of metered customers)	✓	
Ln (length of new mains laid in year / total length of mains at year end)	✓	
Ln (length of mains relined and renewed / total length of mains at year end)	✓	✓
Ln (number of properties below reference pressure level/total properties connected)	✓	
Ln (volume of leakage / total distribution input)	✓	
Ln (number of properties affected by unplanned interruptions > 3 hrs / total properties connected)	✓	
Ln (number of properties affected by planned interruptions > 3 hrs / total properties connected)	✓	
Ln (potable water delivered to billed metered households / total potable water delivered)	✓	
Ln (potable water delivered to billed metered non-households / total potable water delivered)	✓	
Time trend	✓	✓

Source: NERA Adaptation of CMA Bristol Water Final Determination, Appendix 4.

Figure 2.1 presents Ofwat's approach to combining its various models to set the price control for wholesale water totex:

- Ofwat took the average result of its two refined totex models (OLS and random effects), and placed a 33% weight on this in its final cost baseline estimate;
- Ofwat placed a 33% weight on its full (ie. un-refined) totex model;

- Ofwat also placed a 33% weight on its more disaggregated analysis. It took the average of the modelled costs from its two botex models (OLS and random effects), and added modelled enhancement costs to modelled base expenditure to estimate the bottom-up totex component of its triangulation.[6]

At its PR14 Final Determination (FD), Ofwat changed its approach to combining the results of its various models for Bristol Water, recognising that its model did not work sufficiently well in assessing this particular company's relative efficiency. Specifically, Ofwat disregarded the results of its refined totex models, and instead placed a weight of 66% on the its bottom-up modelling to estimate Bristol Water's basic cost threshold for wholesale totex.[7]

Following its assessment of wholesale totex, Ofwat made a series of 'special cost factor' adjustments, to account for company-specific factors with a material effect on costs, and enhancement programmes it considered were "supported by a clear need case" (such as evidence of customer's willingness to pay for new outcomes), and which represented the most cost-beneficial solution.[8]

---

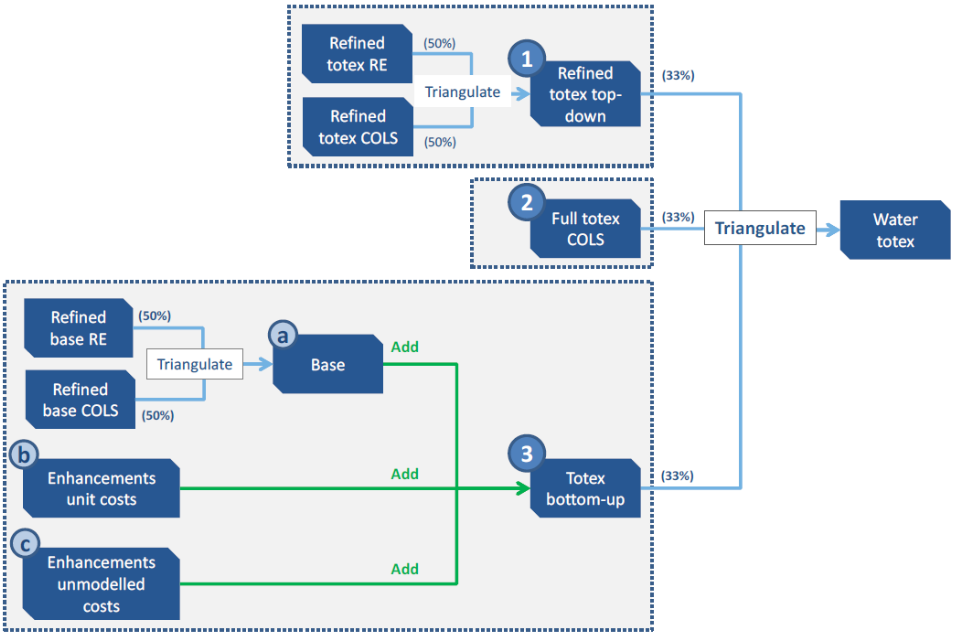
6 Note that Ofwat conducted a unit cost assessment for some enhancement categories, in particular for (1) enhancement expenditure to balance supply and demand; (2) lead reduction costs; and (3) enhancement costs associated with new connections. This component of Ofwat's modelling is labelled "enhancements unit costs" in Figure 2.1 . Ofwat accounted for the remainder of enhancements, labelled "enhancements unmodelled costs", based on a percentage uplift relative to modelled costs. It also considered special cost factor claims from companies to assess efficient levels of enhancement expenditure.

7 The basic cost threshold is Ofwat's estimate of the company's efficient totex for the regulatory period, before accounting for special cost factor adjustments. See:

Ofwat (December 2014), "*Final price control determination notice: policy chapter A3 – wholesale water and wastewater costs and revenues*", p.21.

8 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.A3(1)-2.

Figure 2.1
Estimation Methods and Sets of Explanatory Variables Used in Ofwat Models – Water Service



Source: CEPA/Ofwat (March 2014) "Cost Assessment – Advanced Econometric Models", p.40

2.2. The Bristol Water Referral at PR14

2.2.1. CMA's criticisms of Ofwat's PR14 modelling

At the Bristol Water referral, the CMA considered "that there were significant risks that Ofwat's totex assessment for Bristol Water did not adequately reflect Bristol Water's costs".[9] While the CMA acknowledged the benefits of aggregated totex benchmarking approaches (such as that it limits potential capex biases), it also discussed its concerns with a benchmarking analysis based exclusively on high-level models of base expenditure and totex. Specifically, the CMA raised the following concerns with the Ofwat models:

- **No disaggregation below wholesale water:** Ofwat's models were not disaggregated below the wholesale water level, but covered all parts of the value chain, including water resources, raw water distribution, water treatment, and the distribution of treated water to customers. The CMA noted that complementing such aggregated analysis with more granular models would have had considerable benefits, as granular models "may allow a more accurate estimation of the relationship between expenditure and specific cost drivers and allow a greater number of cost drivers to be taken into consideration".[10]

---

9 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.7.

10 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.70.

- **Timing of investment needs:** Companies’ investment requirements vary over time; and Ofwat’s totex models did not include any explanatory variables to control for differences in the timing of companies’ investment requirements. As a result, Ofwat’s totex benchmarking may mistake differences in companies’ investment cycles for inefficiency.[11]
- **Totex models that include enhancements:** Enhancement expenditure requirements vary across companies (and over time), for instance depending on the supply-demand balance of the service area and the costs of increasing water resource capacity. The CMA considered that Ofwat’s totex models were limited in their ability to account for differences in these enhancement requirements.

To address these problems with Ofwat’s PR14 benchmarking, the CMA recommended that high level regression models should be supplemented with more detailed disaggregated models: [12]

> “The type of high-level totex benchmarking models used by Ofwat carry risks of inaccuracy. We considered that these risks could have been reduced if Ofwat had complemented its analysis with either a more disaggregated or granular benchmarking analysis and/or a more detailed review of companies’ business plans”.

In addition, the CMA identified a number of specific concerns with Ofwat’s econometric benchmarking analysis:[13]

- **Counter-intuitive coefficients**. Some of the estimated coefficients implied relationships between costs and the explanatory variables that suggested a lack of precision in model estimation and limitations in these models. Ofwat’s consultant (CEPA) identified that the results from these models differed from what it had expected, in terms of both the sign (positive or negative) and magnitude of a number of the estimated coefficients.
- **Number of explanatory variables relative to sample size**. The CMA indicated that the small sample size used to estimate Ofwat’s models, combined with a large number of explanatory variables, contributed to the risk of inaccuracy, particularly since some variables were highly correlated with each other and showed little variation over time.

---

11 The CMA notes that Ofwat’s approach of using a five-year rolling average of capex in its dependent variable mitigates but does not eliminate the issue. See:

CMA (October 2015), “*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*”, p.70.

12 CMA (October 2015), “*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*”, p.44.

13 CMA (October 2015), “*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*”, pp. 72-73.

- **Translog models**. Ofwat used models with a particularly complex "translog" specification.[14] The CMA considered that translog models included relatively complex explanatory variables (including cross-product and squared terms), and that "it was difficult to interpret the relationships that they implied between costs and explanatory variables in economic or engineering terms".[15] The CMA argued that the inclusion of these variables seemed to have compromised the results, eg. Ofwat's refined base expenditure models implied a form of diseconomies of scale relative to customer numbers, which the CMA considered to be counter-intuitive.
- **Relationships between costs and cost drivers**. In some cases, the CMA found Ofwat's models were specified in a way that implied a relationship between expenditure and a cost driver that did not make sense, such as taking the logarithms of proportion variables (eg. proportion of distribution input from reservoirs).
- **Endogeneity**. Some of the explanatory variables in Ofwat's models represent factors that were under the control of a company's management to some extent, and should therefore not be treated as independent of the dependent variable in the model, eg. mains renewal and leakage. Given that such workload variables may themselves be reflective of differences in companies' efficiency and working practices, the results of benchmarking analysis may be distorted. However, the CMA considered that, "given limitations in the available data, it may be better, in some cases, to include an explanatory variable that carries risks of endogeneity than to fail to take any account of potentially important differences between companies".[16]

For the reasons outlined above, the CMA decided to develop a set of alternative models in its FD of Bristol Water's PR14 price control.

2.2.2. The CMA's own benchmarking models developed during the Bristol Water referral

The CMA sought to mitigate the issues it identified with Ofwat's PR14 models in developing its own models during the referral process.

The CMA considered an initial set of 18 models, which all sought to estimate the efficient wholesale base expenditure (ie. botex) requirements for Bristol Water at PR14, avoiding totex modelling for the reasons set out in Section 2.2. It used the more straightforward OLS model estimation method, finding that a sensitivity which used random effects produced relatively similar results for Bristol Water.[17]

---

[14] See eg. the variable *Ln (length of mains) * Ln (connected properties / length of mains)* in Table 2.1.

[15] CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", pp. 72-73.

[16] CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", pp. 72-73.

[17] CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", para. 4.99.

The specification of the 18 models was based on the combination of the different modelling options described in Table 2.2 and Table 2.3. Specifically, as shown in Table 2.2, the CMA considered three alternative model forms based on the specification of the dependent variable (logarithmic unit cost, linear unit cost, and logarithmic aggregate), two options for the treatment of capital maintenance costs (smoothed or unsmoothed models), and three alternative sets of explanatory variables (as shown in Table 2.3). All models also used time dummies (for each year of data), which differed from Ofwat's models that included a time trend variable.

Table 2.2
Dimensions in the Specification of the Initial Set of CMA Models

Dimensions	Options Explored in the Initial Set
Model Form	• Logarithmic unit cost models, where the dependent variable is *ln (botex/connected properties)*. • Linear unit cost models, where the dependent variable is *botex/properties*. • Logarithmic aggregate cost models, where the dependent variable is *ln (botex)*.
Dependent Variable	• Smoothed botex (5-year), where botex each year is *(opex in that year)* + *(capital maintenance moving average over five-year period)*. Uses same five-year data sample as Ofwat. • Unsmoothed botex (7-year), where botex each year is *(opex in that year)* + *(capital maintenance in that year)*. Uses longer data period than Ofwat (additional dataset not publicly available).
Explanatory Variables	• Three explanatory variable groups: EV1, EV2 and EV3, described in Table 2.3. • In addition, each model included a constant term and a series of time dummy variables with 2013 as reference year.
Estimation Technique	• Pooled OLS technique.

Source: NERA Summary of CMA Bristol Final Determination.

Privileged and Confidential

Table 2.3
Groups of Explanatory Variables Used in CMA Models

Group	Logarithmic unit cost model	Linear unit cost model	Logarithmic aggregate cost models
EV1	• Ln (water delivered per property) • Ln (regional wage measure) • Ln (mains length per property) • Proportion of distribution input from rivers • Proportion of distribution input from reservoirs • Ln (average pumping head)	• Water delivered per property • Regional wage measure • Mains length per property • Proportion of distribution input from rivers multiplied by water delivered per property • Proportion of distribution input from reservoirs multiplied by water delivered per property • Average pumping head multiplied by water delivered per property	• Ln (water delivered per property) • Ln (regional wage measure) • Ln (total mains length) • Ln (total connected properties divided by total mains length) • Proportion of distribution input from rivers • Proportion of distribution input from reservoirs • Ln (average pumping head)
EV2	As for EV1 plus: • Proportion of water consumption by metered non-household customers	As for EV1 plus: • Proportion of water consumption by metered non-household customers	As for EV1 plus: • Proportion of water consumption by metered non-household customers
EV3	As for EV2 but with rivers and reservoirs variables removed and replaced by: • Proportion of distribution input subject to W3 or W4 treatment	As for EV2 but with rivers and reservoirs variables removed and replaced by: • Proportion of distribution input subject to W3 or W4 treatment multiplied by water delivered per property	As for EV2 but with rivers and reservoirs variables removed and replaced by: • Proportion of distribution input subject to W3 or W4 treatment

Source: NERA Summary of CMA Bristol Final Determination.

From the full set of 18 models, the CMA dropped 11 models which reported counterintuitive coefficients on key variables.[18] As a result, the CMA based its FD cost assessment for Bristol Water on the simple average of seven preferred models. As shown in Figure 2.2, the CMA only used models with a unit cost model specification in its FD, with the explanatory variable sets EV2 or EV3.

[18] CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", paras. 4.148 – 4.152.

Figure 2.2
The CMA's Seven Preferred Models at its PR14 FD for Bristol Water

	Smoothed Botex (5 year)			Unsmoothed Botex (7 year)		
	Log unit cost	Linear unit cost	Log aggreg.	Log unit cost	Linear unit cost	Log aggreg.
Group 1						
Group 2	✓	✓		✓	✓	
Group 3	✓	✓			✓	

Source: NERA Summary of CMA Bristol Final Determination.

However, the CMA also noted that data availability and time constraints restricted its ability to develop improved models:[19]

> "We recognised that these alternative models were imperfect. We did not seek to fully address every aspect of potential model specification that emerged from our own analysis and from the feedback we received from Bristol Water and Ofwat. For instance, it may be possible to develop a further set of alternative models that perform better in statistical terms than the models we used, while also maintaining features that we considered important (eg models that make intuitive sense). Furthermore, the set of alternative models that we used did not exhaust the set of plausible or reasonable models, even on the data available to us".

Hence, the CMA itself highlighted some further improvements compared to its own modelling approach that could be adopted with more time and data.

2.3. Oxera Models Developed in Preparation for PR19

During 2016, Oxera was jointly commissioned by a group of WoCs and WaSCs to develop a set of models in preparation for the PR19 price control. To our knowledge, these models represent the only industry-wide models developed since the last price control.

In conducting this benchmarking work, Oxera assumed that Ofwat will fundamentally change its benchmarking approach for PR19 (relative to its PR14 approach), due to the CMA's criticism of the models and approach it used at PR14 (see Section 2.2), as well as the CMA's recommendation that Ofwat uses more disaggregated modelling and collect and take advantage of a wider range of cost-drivers. Reflecting its assumption that Ofwat will set separate price controls for wholesale water activities for the first time, as Ofwat itself

---

19 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", para. 4.92.

subsequently confirmed in its PR19 Methodology Consultation,[20] Oxera estimated separate benchmarking models for water resource and "network+" activities, covering the rest of the wholesale water value chain.[21]

Oxera used a three-year dataset (released in August 2016 by Ofwat and covering the years 2013/14 and 2015/16) to develop its models. This dataset contained additional cost drivers compared to the PR14 dataset. It also disaggregated companies' opex, capital maintenance and capex costs by value-chain element, attributing costs to either water resources, raw water transport, water treatment or treated water distribution.[22]

Oxera developed various econometric models for base expenditure, at three different levels of cost aggregation by value chain element: [23]

- 8 models for total base expenditure ("aggregate botex"),
- 4 models for water resources botex; and
- 11 models for network+ botex, comprising raw water transport, water treatment and water distribution.

Table 2.4 to Table 2.6 below show the variables used in each of Oxera's models. Oxera's final set of models all use logged costs and logged cost drivers, with the exception of share variables (eg. proportion of water treated at level 3 and above), following the CMA's recommendation at PR14. In common with the CMA, Oxera used only pooled OLS models. Most of Oxera's models are aggregate cost models, however Oxera also developed three unit cost models (one for aggregate botex, water resources, and network plus). In these unit cost models, the dependent variable is divided by the number of properties served.[24]

Oxera excluded some of its network+ and aggregate botex models when calculating a combined view of Bristol Water's efficiency. Specifically, Oxera excluded four network+ models and three aggregate botex models, excluding models which did not control for the share of water treated at level 3 (and above), and models which used distribution input and water delivered as scale drivers, arguing that such models would under-predict Bristol Water's costs due to the low levels of leakage for Bristol Water.[25]

---

[20] Ofwat (July 2017), "Delivering Water 2020: Consulting on our methodology for the 2019 price review", p. 162.

[21] Oxera (January 2017), *"Potential water wholesale cost modelling approaches for PR19 – Industry Study"*, p. 4.

[22] We understand companies have raised concern with the quality of some of the data used. For instance, at the time of Oxera's work, some companies reported errors in average pumping head data.

Oxera (January 2017), *"Potential water wholesale cost modelling approaches for PR19 – Industry Study"*, p. 6.

[23] Oxera (February 2017), *"Approach to refining the model set for Bristol WaterBristol Water"*.

[24] Oxera (February 2017), *"Approach to refining the model set for Bristol WaterBristol Water"*.

[25] Oxera (February 2017), *"Approach to refining the model set for Bristol WaterBristol Water"*, sheet "Network+".

Privileged and Confidential

Table 2.4
Explanatory Variables Included in Oxera's 8 Models for Aggregate Botex

Explanatory Variable	1	2*	3	4	5	6	7	8
Connected properties (log)	✓		✓	✓				✓
Population (log)					✓			
Distribution input (log)						✓		
Water delivered (log)							✓	
Proportion of water treated at level 3 treatment plants							✓	
Proportion of water treated at level 2 treatment plants								✓
Average pumping head (log)	✓	✓	✓	✓	✓	✓	✓	✓
Proportion of mains laid before 1980	✓	✓	✓	✓	✓		✓	
Raw water mains and conveyors/DI (log)	✓	✓			✓	✓	✓	✓
Number of sources over distribution input (log)			✓					
Proportion of distribution input from boreholes				✓				

Note: Model 2 (starred) is a logged unit cost model; all other models are for logged aggregate costs. Oxera excluded models 6, 7 and 8 from its combined efficiency estimate for Bristol Water.

Table 2.5
Explanatory Variables Included in Oxera's 11 Models for Network+ Botex

Explanatory Variable	1	2*	3	4	5	6	7	8	9	10	11
Connected properties (log)	✓		✓	✓	✓	✓	✓	✓			
Population (log)									✓		
Distribution input (log)										✓	
Water delivered (log)											✓
Proportion of water treated at level 3 treatment plants	✓	✓	✓	✓				✓	✓	✓	✓
Proportion of water treated at level 2 treatment plants					✓						
Average pumping head, network+ (log)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Proportion of mains laid before 1980	✓	✓	✓	✓	✓	✓	✓	✓			
Properties over mains (log)			✓								
Properties over company area (log)				✓							
Proportion of distribution input from boreholes						✓					
Proportion of surface water treated							✓				
Mains/connected properties (log)								✓			

Note: Model 2 (starred) is a logged unit cost model; all other models are for logged aggregate costs. Oxera excluded models 5, 6, 10 and 11 from its combined efficiency estimate for Bristol Water.

Table 2.6
Explanatory Variables Included in Oxera's 4 Models for Water Resources Botex

Explanatory Variable	1	2*	3	4
Connected properties (log)	✓		✓	✓
Average pumping head, resources (log)	✓	✓	✓	✓
Proportion of distribution input from boreholes				✓
Raw water mains and conveyors / Dist input (log)	✓	✓		
Number of sources over distribution input (log)			✓	

Note: Model 2 (starred) is a logged unit cost model; all other models are for logged aggregate costs.

3. Updating the Ofwat, CMA and Oxera Models

As a starting point for our benchmarking work to assess the current efficiency position of Bristol Water, we have updated the benchmarking models used at PR14 by Ofwat and the CMA using Ofwat's six-year dataset released in August 2017 ("Ofwat's 2016/17 six-year dataset").[26] We have also updated the results of the models developed by Oxera for PR19. This chapter presents the results we obtain by updating these models.

3.1. Update of Ofwat's PR14 Modelling

In Section 2.1 above, we describe the approach taken by Ofwat to benchmark companies' wholesale water costs in England and Wales. Ofwat used econometric models to benchmark both water companies' total expenditure and base expenditure, and used non-econometric unit cost models and a bottom-up assessment of companies' special cost factor claims to assess companies' enhancement expenditure.

We have updated Ofwat's econometric totex and botex models, using both OLS and random effects, but not its assessment of enhancement expenditure.[27] In order to replicate these models using the updated data, we made the following methodological decisions and assumptions, which differ from Ofwat's approach at PR14:

- Since PR14, Severn Trent Water has merged with Dee Valley Water, and Bournemouth Water has merged with South West Water. We therefore have estimated the Ofwat models using a 16 company panel rather than the 18 company panel used by Ofwat at PR14, merging cost and driver data of the merged companies where necessary.[28]
- Ofwat's dependant variables require the smoothing of capital maintenance and capital enhancement costs over the previous five years. We have therefore partly relied on data from Ofwat's PR14 benchmarking dataset to calculate smoothed costs for 2015 and earlier;
- We have not applied the "alpha adjustment", which Ofwat applied to modelled costs (in models using logged dependent variables). This is consistent with the CMA's approach during the Bristol Water referral and the approach we have used in our own model development (see below).[29]

---

[26] The original version of the dataset was released by Ofwat in August 2017. For the analysis discussed in our report, we have used an updated version of the dataset released by Ofwat in September (filename: "*20170904 hc Master wholesale water July 2017.xlsx*"), which corrected some reporting errors/inconsistencies in the original version of the file.

[27] We have not attempted to reproduce or update Ofwat's assessment of enhancement expenditure for several reasons. Enhancement expenditure is lumpy, and it was assessed by Ofwat based a mix of unit cost assessment, expert judgement of the share of enhancement expenditure that is likely to recur over the next price control period, and based on special cost factor claims submitted by companies. We do not have the data to reproduce this analysis, and the judgements made (eg. on the evaluation of special cost factors claims submitted by companies) involve a high degree of subjectivity. Therefore, we did not reproduce Ofwat's analysis of companies' enhancement programmes.

[28] This approach was necessary since cost data for South West Water and Bournemouth Water was not reported separately in 2016/17.

[29] Note, the CMA found that the application of alpha adjustment made only a very small difference to the results.

- Ofwat's 2016/17 six-year dataset does not contain a regional wage variable, so we have removed this variable from Ofwat's totex and botex models;[30] and
- We understand that Ofwat's classification of water sources has changed since PR14. As a result, the value of some variables such as the proportion of water from reservoirs (and the proportion of water from rivers) has changed relative to the figures reported in the PR14 dataset.[31] We have used the variables as they are reported in Ofwat's 2016/17 six-year dataset.

Table 3.1 shows the results of the models we estimated to update the Ofwat PR14 approach. For totex, the models suggest that Bristol Water is the least efficient company: we estimate an average efficiency gap (to the upper quartile) of 27% or 32% during the period from 2011/12 to 2016/17,[32] depending on the estimation approach (OLS or random effects). For botex, the models suggest Bristol Water is the 14th or 15th placed company (out of 16), with efficiency gaps of 26% and 30% in the OLS and random effects models respectively.

Table 3.1
Efficiency Results for Bristol Water Based on Ofwat's PR14 Models, Updated by NERA

Model		Average Annual Costs (2011/12 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap			Model Passes RESET test?
		Modelled Cost (Pre-UQ Adjustment)	*Actual*	*Delta*		*£*	*%*	*Rank*	
Refined Totex	**RE**	78.22	95.98	17.76	72.95	23.03	**32%**	16	✓
	OLS	77.86	95.98	18.12	75.50	20.48	**27%**	16	
Refined Botex	**RE**	64.37	76.87	12.50	59.12	17.75	**30%**	14	✓
	OLS	63.97	76.87	12.90	60.95	15.92	**26%**	15	

Note: We have omitted Ofwat's "unrefined totex" model, which we have been unable to replicate accurately, since some of the explanatory variables used are no longer reported in Ofwat's 2016/17 six-year dataset.
Source: NERA analysis of Ofwat data.

We also find that the criticisms made by the CMA of Ofwat's PR14 models (see Section 2.2) continue to apply to these updated models. Very few variables in the models are statistically significant. Also, a number of variables, such as share of Distribution Input (DI) from rivers, report counterintuitive and inconsistent coefficients. This may be a consequence of model

CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.64, 86.

30 We note that Ofwat has developed a new regional wage variable, however, this variable does not cover the full six-years included within the 2016/17 six-year dataset. We have therefore not used this variable in our modelling work for Bristol Water.

31 For instance, water which is supplied by a river into a reservoir prior to treatment is now considered to have come from reservoirs, whereas previously it was considered to have come from rivers.

32 We compute efficiency gaps as a percentage of modelled efficient (ie. upper quartile) costs.

over-specification, since Ofwat's models contain a high number of variables relative to the number of observations, some of which are correlated with one-another.[33]

3.2. Update of the CMA Models from the Bristol Water Referral

Section 2.2.2 above describes the approach used by the CMA to benchmark Bristol Water's costs in its determination at PR14. The CMA developed 18 models in total, nine of which modelled smoothed botex costs, and nine which modelled unsmoothed botex costs. In its FD, the CMA used seven of these models to determine Bristol Water's efficiency (see Figure 2.2), without applying an upper-quartile efficiency frontier.

In order to replicate these models using the updated data, we made the same methodological assumptions we made to replicate Ofwat's models, discussed above in Section 3.1. In addition, we understand that the PR14 water treatment level "W3" is closest to the new "level 4" treatment level.[34] Therefore, to update the CMA models, we substitute the PR14 variable proportion of distribution input subject to W3 or W4 treatment with the new variable measuring the proportion of water treated at level 4 complexity or above.

We present the results of our replications of the CMA's unsmoothed botex models in Table 3.2 below, and show the smoothed model results in Table 3.3. Most of the unsmoothed botex models find Bristol Water to be the least efficient company, with an efficiency gap ranging from 28% to 45%. In the CMA's three final models (highlighted in Table 3.2 below), Bristol Water's efficiency gap ranges from 32% to 33%.

Bristol Water's efficiency gap is generally lower in the smoothed botex models than in the unsmoothed models: we estimate an efficiency gap of 32% in the CMA's preferred unsmoothed models, compared to a 25-27% gap in the CMA's final four smoothed models. We also find that Bristol Water performs better in unit cost models than in aggregate cost models, across both the smoothed and unsmoothed model specifications.

33 We present the detailed regression outputs, including coefficients estimates and t-values, from our re-run of the Ofwat models in Appendix B.1.

34 Ofwat has revised its classification of water treatment complexity since PR14, and as such the new water treatment levels are not directly comparable with those used at PR14.

Privileged and Confidential

Table 3.2
Efficiency Results for Bristol Water Based on the CMA's Unsmoothed PR14 Models, Updated by NERA

Model		Average Annual Costs (2011/12 to 2016/17) Modelled Cost (Pre-UQ Adjustment)	Actual	Delta	Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap £	%	Rank	Model Passes RESET test?
Logged unit cost	EV1	62.81	78.46	15.65	59.50	18.96	**32%**	16	×
	EV2*	62.30	78.46	16.15	59.23	19.23	**32%**	16	×
	EV3	66.92	78.46	11.54	61.38	17.08	**28%**	13	×
Linear unit cost	EV1	64.18	78.46	14.28	60.13	18.33	**30%**	16	×
	EV2*	63.64	78.46	14.82	59.39	19.07	**32%**	16	×
	EV3*	66.14	78.46	12.32	59.54	18.91	**32%**	16	×
Logged agg. cost	EV1	60.27	78.46	18.18	55.54	22.92	**41%**	16	×
	EV2	59.24	78.46	19.22	54.08	24.38	**45%**	16	×
	EV3	63.77	78.46	14.69	59.29	19.17	**32%**	15	✓

Notes: Highlight denotes final models selected by the CMA for determining Bristol Water's efficiency.
Source: NERA Analysis of Ofwat data.

Table 3.3
Efficiency Results for Bristol Water Based on the CMA's Smoothed PR14 Models, Updated by NERA

Model		Average Annual Costs (2011/12 to 2016/17) Modelled Cost (Pre-UQ Adjustment)	Actual	Delta	Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap £	%	Rank	Model Passes RESET test?
Logged unit cost	EV1	65.02	76.87	11.85	61.12	15.75	**26%**	16	×
	EV2*	64.72	76.87	12.15	61.30	15.57	**25%**	16	✓
	EV3*	67.61	76.87	9.26	61.60	15.27	**25%**	13	✓
Linear unit cost	EV1	65.69	76.87	11.18	60.86	16.01	**26%**	14	×
	EV2*	65.33	76.87	11.54	61.09	15.78	**26%**	16	✓
	EV3*	66.51	76.87	10.36	60.44	16.43	**27%**	14	✓
Logged agg. cost	EV1	62.75	76.87	14.12	58.04	18.83	**32%**	16	✓
	EV2	62.03	76.87	14.84	57.03	19.84	**35%**	16	✓
	EV3	65.45	76.87	11.42	60.30	16.57	**27%**	14	✓

Notes: Highlight denotes final models selected by the CMA for determining Bristol Water's efficiency.
Source: NERA Analysis of Ofwat data.

We find that the smoothed models, which produce lower efficiency gaps for Bristol Water, also perform better statistically. In particular, 8 of the CMA's 9 unsmoothed models fail the Ramsey RESET test for model specification, a key econometric test used by Ofgem for its model selection at the RIIO-ED1 price control for the British electricity distribution network operators.[35] By contrast, the majority of the CMA's smoothed models, and all of the CMA's preferred smoothed models, pass this key test for model specification.

However, we find that some explanatory variables exhibit inconsistent and counterintuitive coefficients in the various models. For instance, the coefficient of average pumping head (and average pumping head per unit of water delivered per property) is negative in each of the EV3 unit cost models for both smoothed and unsmoothed botex. In selecting its preferred models, the CMA considered carefully if the coefficient estimates (and thus the implied relationships between costs and driver) were logical based on engineering and economic intuition. It excluded models from its final set of preferred models if the models failed these tests of economic intuition. As such, 4 out of the CMA's 7 preferred models would not pass the CMA's own model selection criteria, based on the regression results using the new data.[36]

We therefore conclude that the CMA's PR14 models are not fit for use at PR19, because:

1. Many of the CMA's preferred models fail the Ramsey RESET test for model specification, implying that these models may be mis-specified;
2. The majority of the CMA's preferred models would not pass the CMA's own model selection criteria based on the updated data, due to the counterintuitive relationships implied between cost drivers and costs; and
3. The CMA itself recommended improvements to its models (such as the use of more disaggregated benchmarking to assess companies' relative efficiency), which it could not apply at the time of the price control due to data limitations.

3.3. Update of Oxera's Models Developed in Preparation for PR19

As described above, in preparation for PR14, Oxera has developed a set of 8 aggregate botex models, as well as 11 network+ botex models, and 4 water resources botex models. We have updated Oxera's models using the six-year dataset. Our econometric approach follows the approach we have used in replicating the CMA models and Ofwat's OLS models.

We present the results of our replication of Oxera's aggregate botex models in Table 3.4.[37] Bristol Water is ranked between 12th and 15th, with gaps ranging between 23% and 44%. Bristol Water performs best in model 4, the only model to control for the proportion of DI

[35] The Ramsey RESET test was used by Ofgem at RIIO-ED1 to assess whether the model under consideration was misspecified (ie. whether the specified functional form was incorrect). The test involves re-running the original model, but with powers of the fitted values of the dependent variable included as explanatory variables in the regressions. If the coefficients on these added explanatory variables are found to be statistically significantly different from 0, the model fails the Ramsey RESET test for model specification.

Ofgem (November 2014), "*RIIO-ED1: Final determination for the slow-track electricity distribution companies – Business plan expenditure assessment",* pp. 187, 190.

[36] We present the detailed regression outputs, including coefficients estimates and t-values, from our re-run of the CMA models in Appendix B.2.

[37] We have also estimated the efficiency gaps and rankings for the other water companies, based on Oxera's models. We present these results, in summary form, in Appendix A.2.

from boreholes (ie. controlling for differences in raw water sources across companies). Bristol Water performs worst in models 6 and 7.

Table 3.4
Summary of Bristol Water's Efficiency in NERA's Replication of the Oxera's Aggregate Botex Models

Model	Average Annual Costs (2011/12 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap			*Model Passes RESET test?*
	Modelled Cost (Pre-UQ Adjustment)	*Actual*	*Delta*		*£*	*%*	*Rank*	
1	68.95	78.46	9.51	62.14	16.32	**26%**	13	×
2*	70.02	78.46	8.44	63.05	15.41	**24%**	12	×
3	63.84	78.46	14.62	57.55	20.91	**36%**	14	×
4	70.37	78.46	8.09	63.97	14.49	**23%**	13	×
5	68.29	78.46	10.17	62.46	16.00	**26%**	14	×
6	62.01	78.46	16.45	56.18	22.28	**40%**	15	×
7	61.70	78.46	16.76	54.48	23.98	**44%**	15	×
8	67.10	78.46	11.36	58.71	19.75	**34%**	13	×

Notes: Model 2 (starred) is a unit cost model; all other models are for aggregate costs. Oxera excluded models 6, 7 and 8 from its combined efficiency estimate for Bristol Water.
Source: NERA Analysis of Ofwat data.

We present results of Oxera's network+ model in Table 3.5 below. Bristol Water ranks between the 10th and 14th most efficient company, with efficiency gaps of between 15% and 38%. From this range of models, Bristol Water's efficiency gap is smallest in model 7, which controls for the proportion of surface water treated out of total water treated, and model 2, a unit cost model. Bristol Water's efficiency gap is largest in models 10 and 11, which do not control for proportion of mains laid before 1980.

Table 3.6 summarises the results of Oxera's water resources models. Bristol Water is the lowest ranked company in all four models, with a narrow range of efficiency gaps between 103% and 111%. In other words, these models suggest that Bristol Water's efficient costs in water resources are less than half its actual costs.

Privileged and Confidential

Table 3.5
Summary of Bristol Water's Efficiency in NERA's Replication of the Oxera's Network+ Models

Model	Average Annual Costs (2011/12 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap			*Model Passes RESET test?*
	Modelled Cost (Pre-UQ Adjustment)	*Actual*	*Delta*		*£*	*%*	*Rank*	
1	59.33	64.41	5.08	52.32	12.09	**23%**	12	×
2*	60.73	64.41	3.68	53.43	10.98	**21%**	12	×
3	58.11	64.41	6.31	51.34	13.07	**25%**	11	×
4	58.54	64.41	5.87	50.69	13.72	**27%**	11	×
5	59.53	64.41	4.89	51.82	12.59	**24%**	12	×
6	57.97	64.41	6.45	52.19	12.23	**23%**	12	×
7	62.15	64.41	2.27	55.99	8.42	**15%**	10	×
8	55.75	64.41	8.67	47.21	17.20	**36%**	13	×
9	56.86	64.41	7.56	51.19	13.22	**26%**	14	×
10	53.45	64.41	10.97	47.29	17.13	**36%**	14	×
11	51.90	64.41	12.51	46.64	17.77	**38%**	14	×

Notes: Model 2 (starred) is a unit cost model; all other models are for aggregate costs. Oxera excluded models 5,6, 10 and 11 from its combined efficiency estimate for Bristol Water.
Source: NERA Analysis of Ofwat data.

Table 3.6
Summary of Bristol Water's Efficiency in NERA's Replication of Oxera's Water Resources Models

Model	Average Annual Costs (2011/12 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap			*Model Passes RESET test?*
	Modelled Cost (Pre-UQ Adjustment)	*Actual*	*Delta*		*£*	*%*	*Rank*	
1	7.95	14.04	6.09	6.67	7.38	**111%**	16	✓
2*	8.00	14.04	6.04	6.71	7.34	**109%**	16	✓
3	7.76	14.04	6.28	6.71	7.34	**109%**	16	✓
4	8.01	14.04	6.04	6.93	7.11	**103%**	16	✓

Notes: Model 2 (starred) is a unit cost model; all other models are for aggregate costs.
Source: NERA Analysis of Ofwat data.

We find that there are several statistical problems with Oxera's models. All its aggregate botex and network+ models fail the Ramsey RESET for model specification, and some of the explanatory variables used by Oxera do not produce consistent or intuitive coefficients. For instance, average pumping head, which appears in all of Oxera's models, is negative in 17 of Oxera's 23 models for aggregate botex, network+ and water resources.[38]

Oxera's models also include only a relatively low number of explanatory variables (the majority of models include 3 or 4 explanatory variables), suggesting that Oxera may fail to control for important cost drivers in its models. While including a high number of cost drivers is not appropriate when the dataset is small, due to risks around unstable (or counterintuitive) coefficients (as discussed by the CMA), including too few explanatory variables may result in the models omitting important cost drivers. This potential omission of relevant cost drivers may explain the finding that the Ramsey RESET test indicates that Oxera's models are mis-specified, and hence that its coefficient estimates and efficiency scores may be biased.

Oxera's models also fail to control for various cost drivers that capture Bristol Water's differentiating characteristics and control for Bristol Water's relatively high expenditure in certain areas. For instance, Oxera's models do not include variables to control for Bristol Water's high water treatment complexity or the high share of surface water relative to the industry as a whole. We discuss Bristol Water's company-specific characteristics in more detail in our separate report on special cost factors.

In summary, while Oxera's models represent the only benchmarking models developed for wholesale water since PR14, these models are not statistically robust, and do not account for Bristol Water's differentiating characteristics.

3.4. Conclusion on the existing benchmarking models

In this Chapter, we have replicated the results of the benchmarking models used by Ofwat at PR14, the CMA at Bristol Water's PR14 referral, and the models developed by Oxera in preparation for PR19. We have concluded that these models are not fit for use at the PR19 price control, for several reasons. In particular:

- Ofwat's PR14 models are not statistically robust for a range of reasons, including those cited in the CMA's Final Determination for Bristol Water;
- The CMA's PR14 models are also not robust, because the majority of models fail the Ramsey RESET test for model specification, a key test for model selection also used by Ofgem at the RIIO-ED1 price control. The CMA itself also recommended improvements to its own models, such as the use of more disaggregated modelling to benchmark costs as it was not able to conduct this additional modelling due to time and data constraints during the PR14 referral process.
- Oxera's models are not robust because they, like the CMA's models, fail the Ramsey RESET test for model specification. Oxera's models also fail to control for particular characteristics important to explaining Bristol Water's costs, which means that these

[38] We present the detailed regression outputs, including coefficients estimates and t-values, from our re-run of the Oxera models in Appendix B.3.

models are not appropriate for estimating Bristol Water's efficiency, at least without applying special cost factor claims.[39]

Given these limitations associated with existing models, we have developed our own, more statistically robust, models to benchmark companies' wholesale water costs. As we discuss in Chapter 4, these models also aim to control for the environmental and operational factors that explain Bristol Water's relatively high costs in certain areas, such as water treatment complexity.

39 Oxera's models represent the only known suite of benchmarking models which seek to take an industry perspective of wholesale water since PR14. As Oxera's modelling work was commissioned by a group of water companies, these models sought to balance the views of the participating companies as to the most appropriate cost drivers to include in the benchmarking models.

4. Developing More Robust Benchmarking Models

As discussed in Chapter 3, we have developed our own benchmarking models that seek to address some of the problems associated with the PR14 and Oxera models. As described below, these models are both more statistically robust than the PR14 and Oxera models described above, and better account for the environmental and operational factors that influence Bristol Water's costs.

4.1. Methodological Choices

4.1.1. Choices of dependent variable and the level of cost aggregation

We have developed benchmarking models for Bristol Water that explain the variation in companies' base expenditure. We have not conducted totex benchmarking, due to the lumpiness of enhancement expenditure, which may distort modelled coefficients and efficiency gaps/rankings. As Ofwat acknowledges, enhancement expenditure can be "quite company-specific, irregular and difficult to predict",[40] so totex models run the risk of mistaking differences between companies' enhancement expenditure requirements for efficiency or inefficiency. The CMA discusses further reasons that explain why totex benchmarking may be risky:

> "Where companies needed to increase water resource capacity, the costs of doing so may vary substantially between companies depending on local, ecological and environmental factors that determine the feasible options for additional water resources and their costs. Enhancement requirements may also be driven by relatively local environmental concerns, such as over-abstraction from particular sources, which vary across different companies' regions".[41]

We understand from Ofwat's methodology consultation that Ofwat is planning to use totex econometric approaches at PR19, where appropriate, while recognising that (1) "enhancement expenditure, in most cases, has unique cost drivers"; and (2) there is less data for the robust benchmarking of enhancement expenditure, as these activities are not routine.[42] Specifically, Ofwat proposes to "include elements of the enhancement programme in [its] econometric benchmarking models", where appropriate, and assess other elements of enhancements (where econometric tools are less appropriate) separately.[43]

Hence, because we have not conducted detailed analysis of companies' enhancement expenditure, we have focused this study on botex. Specifically, we have attempted to develop botex benchmarking models at six different levels of aggregation by value chain element:

---

40 Ofwat (July 2017), "Delivering Water 2020: Consulting on our methodology for the 2019 price review", p. 175.

41 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", pp.70.

42 Ofwat (July 2017), "Delivering Water 2020: Consulting on our methodology for the 2019 price review", p. 162.

43 Ofwat (July 2017), "Delivering Water 2020: Consulting on our methodology for the 2019 price review", p. 176.

1. Aggregate (ie. across all value chain elements);
2. Water resources;
3. Network plus (ie. the across raw water transport, water treatment, and treated water distribution);
4. Raw water transport;
5. Water treatment;
6. Treated water distribution.

Our approach of modelling costs at a more disaggregated level is in line with the CMA's recommendations at Bristol Water's PR14 appeal to use more disaggregated models in the benchmarking assessment:

> "Disaggregated models or more granular forms of benchmarking analysis may allow a more accurate estimation of the relationship between expenditure and specific cost drivers and allow a greater number of cost drivers to be taken into consideration".[44]

Our approach also follows the guidance of Ofwat's PR19 methodology consultation, as Ofwat has confirmed that it will set separate binding price controls for the water resources and network+ elements of the wholesale water value chain.[45] Ofwat has also signalled it plans to use a mix of aggregated and disaggregated benchmarking models:

> "We [Ofwat] propose to develop a richer set of benchmarking models relative to what we had in PR14. Our benchmarking analysis will include "top down" models that compare aggregate wholesale costs across companies, similar to those used in PR14. We also propose to develop granular models. The granular models will benchmark expenditure on individual services, such as, treatment, distribution, water resources and bioresources".[46]

4.1.2. Functional form

We considered using logarithmic and linear model specifications. We have not considered using translog model forms, which were used by Ofwat at PR14, but were subsequently criticised by the CMA at the Bristol Water referral (see above).

We considered that logarithmic models (which imply a Cobb-Douglas functional form) better capture the theoretical relationships we would expect between costs and drivers than linear models. Logarithmic models imply proportional relationships between costs and drivers, whereas linear models imply absolute relationships.[47]

---

44 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.70.

45 Ofwat (July 2017), "*Delivering Water 2020: Consulting on our methodology for the 2019 price review*", p. 162.

46 Ofwat (July 2017), "*Delivering Water 2020: Consulting on our methodology for the 2019 price review*", p. 174.

47 For instance in a linear model specification, an increase of 1 million cubic metres in distribution input would result in a set increase in costs (as measured in pounds) based on the model, independent of the level of DI (or the size of the

The Cobb-Douglas functional form also has practical advantages for the econometric analysis: it works well with small sample sizes and, unlike the translog model, allows for the inclusion of a relatively high number of independent cost drivers. A recent report prepared for United Utilities by Vivid Economics and ARUP has also recommended the use of the Cobb-Douglas functional form for benchmarking in the water industry.[48]

Following the CMA's recommendation at PR14, we have not taked the logarithm of proportion variables. We do take logarithms of all other drivers. This approach implies more economically intuitive relationships between drivers and costs than taking the logarithm of all explanatory variables.[49]

4.1.3. Unit cost vs. aggregate models

We considered using unit cost and aggregate cost models. Unit cost models explain the variation in costs per connected property, while aggregate cost models explain variation in the level of costs. We consider that unit cost models are more appropriate, because reduce the challenges associated with multicollinearity between various explanatory variables that control for differences in companies' scale.[50] Specifically, aggregate models require the inclusion of scale drivers to control for differences between the size of different water companies (ie. their scale of activities). However, these scale drivers may be closely correlated, so including multiple relevant scale drivers could lead to unstable and/or counterintuitive model coefficient estimates due to multicollinearity.

This choice is also in line with the CMA's PR14 determination. The CMA considered using logarithmic aggregate cost models (in addition to linear and logarithmic unit cost models). Out of a total of 18 models considered, the CMA chose 7 preferred models, none of which were models of logarithmic aggregate costs.[51]

4.1.4. Smoothing of capital maintenance costs

We considered whether to "smooth" capital maintenance costs when preparing companies botex cost data to feed into models. During our model development process (discussed

---

company). By contrast, a logarithmic model specification assumes proportional relationships, ie. that due to 1 percent increase in distribution input, costs will increase by a certain percent (for instance 0.6 percent).

48 Vivid Economics & ARUP (2017), "*Understanding the exogenous drivers of wholesale wastewater costs in England and Wales",* p.6.

49 For instance, including a logged share variable such as the share of DI from reservoirs would imply that a change in the reservoir share of DI from 5% to 10%, and a change from 40% to 80% would have the same percentage impact on costs, which is clearly counterintuitive. For the CMA's discussion of the issue around logged proportion variables, please see:

CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. A4(1)-38.

50 "High (but not perfect) correlation between two or more independent variables is called multicollinearity". See:

Wooldridge (2012), "*Introductory Econometrics: A modern approach*", 5th Edition, p.95.

51 In other words, all of the CMA's preferred models were unit cost models. See: CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p.100.

further below) we identified that models based on unsmoothed costs tended to perform poorly statistically.

Specifically, we found that models with unsmoothed costs tended to fail the Ramsey RESET test for model specification, while models based on smoothed costs did not suffer from this shortcoming, suggesting that models for unsmoothed botex may be misspecified.

We found a similar result when replicating the CMA's seven preferred models. As discussed in Section 3.2, we found that all 3 models with unsmoothed botex as the dependent variable fail the Ramsey RESET test, while the 4 models with smoothed botex all pass this test. We therefore concluded that using smoothed botex is more appropriate for the benchmarking assessment. As such, we developed models with smoothed capital maintenance expenditure.

4.1.5. Temporal effects

Cost benchmarking models, such as those discussed in Chapter 2, typically control for changes in cost conditions over time that affect the whole industry. We used dummy variables for each year in our regressions to control for such effects. We considered time dummy variables were more appropriate than a time trend variable, since factors that affect all companies simultaneously (such as movements in input prices) may lead to year-on-year fluctuations in costs rather than an upward or downward trend. This approach was also adopted by a recent report on benchmarking methods for wholesale wastewater, commissioned by United Utilities,[52] and also follows the CMA's approach from PR14:

> "There may be year-to-year fluctuations in costs across the industry, associated with the price control periods or input price movements, which do not fit well with an upward or downward time trend and which may be better accommodated through a model specification using time dummies".[53]

4.1.6. Estimation technique

When conducting benchmarking regressions, a choice is required as to the technique that is used to estimate model coefficients and thus compute efficiency gaps. The most commonly used technique in benchmarking studies by UK regulators is Ordinary Least Squares (OLS). However, Ofwat also estimated "random effects" Generalised Least Squares (GLS) estimators at PR14.[54] However, it is not robust when using small datasets.[55] We have therefore used the OLS regression technique, in line with the CMA's approach at Bristol

---

[52] Vivid Economics & ARUP (2017), "*Understanding the exogenous drivers of wholesale wastewater costs in England and Wales",* p.6.

[53] CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. A4(2)-22.

[54] This is a regression technique that accounts for the panel structure of the data (ie. that the dataset includes observations for a set of companies over time). It corrects for issues around the correlation of error terms and heteroskedasticity, and separates the error term into an idiosyncratic and a company-specific error, which has a solid theoretical justification, because our dataset includes observations on sixteen companies over time.

[55] Vivid Economics & ARUP (2017), "*Understanding the exogenous drivers of wholesale wastewater costs in England and Wales",* p.38.

Water's PR14 appeal and also in line with Ofgem's approach at the RIIO price controls.[56] In any event, the CMA also found that the differences between the results of the OLS and GLS models were fairly small for Bristol Water, and therefore considered that it is "more important to examine other aspects of model specification than the choice between random effects and OLS models".[57]

Following both the CMA and Ofgem approaches, we estimated our pooled OLS regressions with cluster-robust standard errors (clustered by company), which account for the possible heteroskedasticity and autocorrelation of the standard error (which could result from the panel data structure).[58]

We have not considered the use of other modelling techniques, such as Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) due to data limitations. Ofgem exclusively used the pooled OLS technique at RIIO-ED1, and argued against the use of SFA (and RE) techniques due to the limited time-series variation in company panel data:

> "As there is very limited time-series variation compared to cross sectional variation in the data we do not consider that the use of RE or SFA techniques would be appropriate in our case".[59]

4.2. Model Selection Process

4.2.1. Identification of candidate cost drivers

As a first step in our model selection process, we began by identifying a list of candidate cost drivers for each value chain element. We identified this long list based on economic and engineering intuition, ie. an understanding of which variables can be expected to drive water companies' costs in water resources, raw water transport, water treatment, and treated water distribution. We only considered variables included in Ofwat's 16/17 six-year dataset. In preparing this long list of candidate cost drivers, we also reviewed the cost drivers used by Ofwat and the CMA at PR14 and by Oxera.

We present our list of candidate cost drivers in Table 4.1 below. The table shows which cost drivers we considered relevant for which element of the value chain. For instance, the length of raw mains and conveyors (over DI) is a relevant cost driver for water resources and raw water transport costs, but we assume it does not drive costs in water treatment or treated water distribution.

---

56 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. 85. and Ofgem (November 2014), "*RIIO-ED1: Final determination for the slow-track electricity distribution companies – Business plan expenditure assessment",* p. 184.

57 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. 85.

58 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. A4(2)-50.

59 Ofgem (December 2013), *"RIIO-ED1 business plan expenditure assessment - methodology and results"*, p. 26.

Privileged and Confidential

Table 4.1
Our Long List of Candidate Explanatory Variables, by Value Chain element

Variables	Water Resources	Raw water transport	Water treatment	Distribution
Ln (connected properties)	✓	✓	✓	✓
Ln (length of mains/ connected properties)				✓
Ln (DI/ connected properties)	✓	✓	✓	✓
Ln (water delivered/ connected properties	✓	✓	✓	✓
Ln (population/ connected properties)	✓	✓	✓	✓
Ln (average pumping head – value chain element-specific)	✓	✓	✓	✓
Ln (nr of sources/ DI)	✓	✓	✓	✓
Ln (water treatment works/ DI)		✓	✓	✓
Ln (length of raw mains and conveyors/ DI)	✓	✓		
Share of water treated at level 2 or above			✓	
Share of water treated at level 3 or above			✓	
Share of water treated at level 4 or above			✓	
Share of water treated at level 5 or above			✓	
Surface water treated/ Total water treated	✓	✓	✓	
Length of mains pre-1880/ Total length of mains				✓
Length of mains pre-1900/ Total length of mains				✓
Length of mains pre-1920/ Total length of mains				✓
Length of mains pre-1940/ Total length of mains				✓
Length of mains pre-1960/ Total length of mains				✓
Length of mains pre-1980/ Total length of mains				✓
Length of renewed and relined mains/ Total length of mains				✓
Proportion of water from boreholes	✓	✓	✓	
Proportion of water from rivers	✓	✓	✓	
Proportion of water from reservoirs	✓	✓	✓	
Water delivered to non-households/ Total water delivered	✓	✓	✓	✓
Metered properties/ Total nr of properties	✓			✓
Leakage/ Distribution input		✓		✓

4.2.2. The general-to-specific approach to model selection may not be appropriate due to the high number of candidate cost drivers

After identifying potentially relevant explanatory variables, we then need to test whether each of the candidate drivers listed above does actually exhibit a statistical relationship with costs, and to refine the long list of drivers.

One approach to achieving this in practice is to apply a “general-to-specific” approach: this entails running an initial regression with a wide range of relevant explanatory variables, and then dropping variables from the model based on statistical tests and statistical significance. For instance, explanatory variables with counterintuitive coefficients, or coefficients that are not statistically significant, may be removed from the regression. This requires an iterative process: for instance, the statistical significance of some coefficients may depend on the inclusion of certain other explanatory variables, and the outcome may depend on the order in which candidate drivers are excluded from the model.

One particular issue with the general-to-specific approach can be multicollinearity (ie. high correlation between two or more explanatory variables), which can lead to counterintuitive coefficients estimates. The general-to-specific approach does not provide guidance to the modeller on which explanatory variables to exclude from the regression in the presence of multicollinearity from the pool of variables that are closely correlated. This challenge is particularly acute given the relatively small sample size we have in Ofwat's 2016/17 six-year dataset.

We therefore considered that the general-to-specific approach was not appropriate for our model development in this context.

4.2.3. Instead, we used a Monte Carlo simulation approach to refine the list of candidate cost drivers

Given these limitations of the general-to-specific approach, we developed a Monte Carlo approach to identify which cost drivers from the long list of explanatory variables explain most variation in companies' costs and are likely to produce an economically and statistically robust model (passing diagnostic tests, intuitive coefficients, relatively high R-squared, etc.).

Our Monte Carlo analysis involved the following steps:

1. We ran 4000 regressions for each value chain element, by randomly selecting explanatory variables from the corresponding long list of candidate drivers:
2. We screen the 4000 regressions (for each value chain element) based on statistical tests and other criteria and adopt the following screening criteria for the randomly generated models:
   A. Regressions should pass the Ramsey RESET test at the 5% significance level;
   B. Regressions should have an adjusted R-squared of at least 20%;[60] and
   C. Coefficients for a small number of variables (specifically DI per property, water delivered per property, share of water treated at or above level 4 and level 5 water treatment complexity) should have the expected sign.
3. We then run additional regressions to identify which drivers drive "good model outcomes":

[60] The adjusted R-squared of the CMA's unit cost models at PR14 fell between 21% and 43%. See:

CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. A4(2)-51.

Privileged and Confidential

A. We run an OLS regression of estimated adjusted R-squared on a list of dummy variables (one for each candidate cost driver for the specific value chain element), which capture whether or not the given cost driver was included in each randomly generated model. We run this regression using only models that pass our screening criteria, as discussed above. Coefficient estimates from this regression capture the impact of including the given explanatory variable on the explanatory power (ie. the adjusted R-squared) of the model.

B. We also run a logit regression that tests how the inclusion of individual drivers affects the likelihood of a model passing our selection criteria.

Below, we present the results of this analysis for each of the value chain elements, and set out how we developed our models for Bristol Water based on these results.

4.3. Developing Total Botex Models

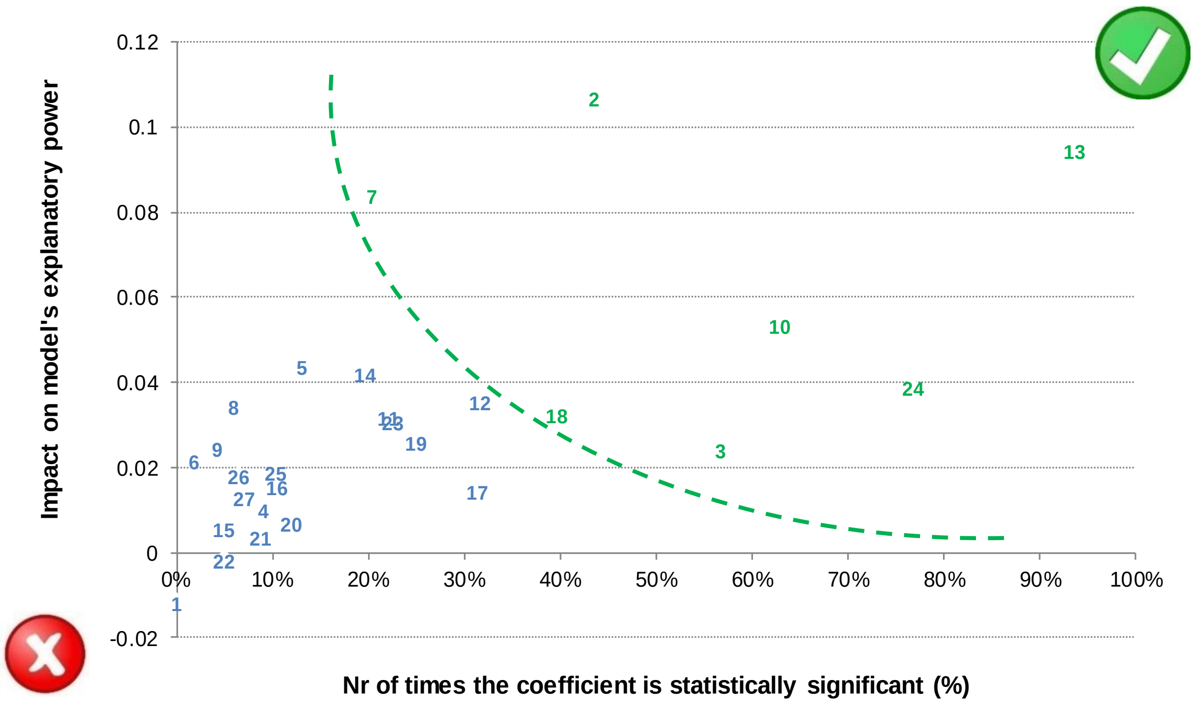
4.3.1. Monte Carlo analysis for total botex

Figure 4.1 and Figure 4.2 summarise the results of our Monte Carlo analysis for total botex. On the vertical axis, Figure 4.1 shows a scatter plot capturing comparing the impact of including each candidate driver on the model's adjusted R-squared (derived from the regression in Step 3A), against the proportion of randomised models in which each driver had a statistically significant coefficient (on the horizontal axis). We considered those drivers towards the top-right corner of Figure 4.1 , which increase R-squared substantially and are also often found to be statistically significant, when specifying our final models in order to improve the overall fit of the model.

Also, in Figure 4.2 we present the odds ratios from the logit model (Step 3B), which captures the likelihood of models passing our model selection criteria, conditional on each variable being included. For instance, we estimate an odds ratio of about 50 for the variable 'share of water treated at level 5 and above'. This means that, if we include this cost driver, a model is 50 times more likely to pass our model selection criteria than it we do not include it. We considered those drivers with high odds ratios when specifying our final models in order to improve the likelihood of estimating a robust model.

Privileged and Confidential

Figure 4.1
Assessment of Candidate Explanatory Variables - Total Botex



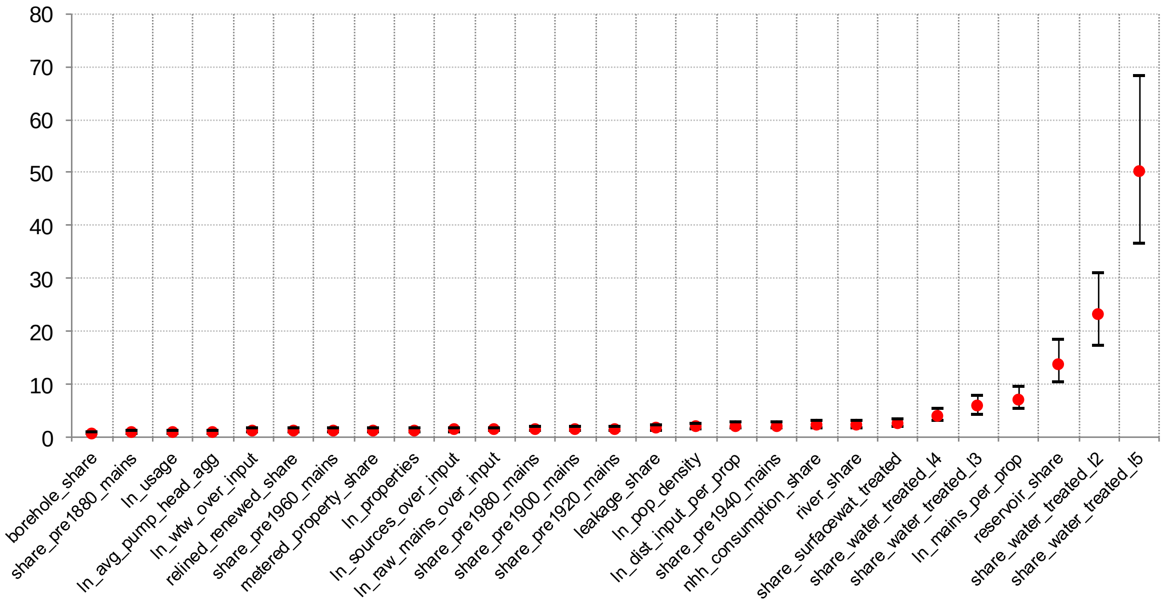
Driver Description

1 Ln (connected properties)
2 **Ln (length of mains/ connected properties)**
3 **Ln (DI/ connected properties)**
4 Ln (water delivered/ connected properties)
5 Ln (population/ connected properties)
6 Ln (average pumping head)
7 **Ln (nr of sources/ DI)**
8 Ln (water treatment works/ DI)
9 Ln (length of raw mains and conveyors/ DI)
10 **Water treated at level 2 or above**
11 Water treated at level 3 or above
12 Water treated at level 4 or above
13 **Water treated at level 5 or above**
14 Surface water treated/ Total water treated
15 Length of mains pre-1880/ Total length of mains
16 Length of mains pre-1900/ Total length of mains
17 Length of mains pre-1920/ Total length of mains
18 **Length of mains pre-1940/ Total length of mains**
19 Length of mains pre-1960/ Total length of mains
20 Length of mains pre-1980/ Total length of mains
21 Length of renewed and relined mains/ Total length of mains
22 Proportion of water from boreholes
23 Proportion of water from rivers
24 **Proportion of water from reservoirs**
25 Water delivered to non-households/ Total water delivered
26 Metered properties/ Total nr of properties
27 Leakage/ Distribution input

Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

Privileged and Confidential

Figure 4.2
Assessment of Candidate Explanatory Variables - Total Botex
Odds Ratios of Models Passing Selection Criteria, from the Inclusion of the Given Driver



Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.3.2. Short list of candidate cost drivers for our total botex models

Based on our Monte Carlo analysis, we consider the following drivers when specifying our final models:

- Variables capturing differences in water treatment complexity, and especially the share of water treated at WTWs of complexity level 5 and above;[61]
- The share of water originating from reservoirs[62] or rivers;
- Logarithm of 'DI over connected properties';
- Logarithm of 'the length of mains over connected properties';

61 The 'share of water treated at WTWs of complexity level 5 and above' seems to be a key driver of water companies' costs. This variable is found to be statistically significant in over 90% of our regressions, and, by including this variable in a regression model, the explanatory power (adjusted R-squared) of the model is estimated to increase by 10 percentage points. We estimate an odds ratio of 50 for this cost driver, suggesting that models that include the share of water treated at level 5 (and above) as a cost driver are 50 times more likely to pass our model selection criteria than models that do not. Other treatment complexity variables (such as the share of water treated at level 2 and above) also seem to be important drivers of companies' costs.

62 The share of distribution input from reservoirs is also a key driver of companies' costs. It is found to be statistically significant about 80% of the time and improves the explanatory power of the model.

- Logarithm of 'the number of raw water sources over DI';
- Network age variables, and in particular the variable 'share of pre 1940 mains; and
- Surface water treated over total water treated (ie. the share of surface water).

In addition to these variables, we considered that there was a strong theoretical justification for including certain additional drivers in the final stage of our model selection process. Specifically, we have included the below three drivers in our short list of candidate cost drivers for total botex:

- Logarithm of average pumping head, on the basis that a higher average pumping head leads to higher total botex, due to higher pumping costs;
- Share of renewed and relined mains (ie. the length of mains relined and renewed in the given year, over total length of mains): This is a key volume driver of capital maintenance costs. While this variable is under management control, we consider that it is a key driver that controls for differences in workload across companies. The CMA, while critical of the inclusion of explanatory variables under direct management control, also stated at Bristol Water's PR14 appeal that, "given limitations in the available data, it may be better, in some cases, to include an explanatory variable that carries risks of endogeneity than to fail to take any account of potentially important differences between companies".[63] Volume drivers have also been used in recent regulatory price controls in the UK. For instance, Ofgem used the following volume drivers at its RIIO-ED1 price control for the GB electricity DNOs:
  - The volume of spans cut and inspected as a cost driver for tree cutting costs; and
  - The number and type of network faults as a driver of faults costs;
- Logarithm of 'the length of raw mains and conveyors over DI': While the analysis does not suggest that the length of raw mains over DI is a key driver of costs, we consider that economic and engineering logic suggests that we should include this driver in our short-list of candidate explanatory variables.

4.3.3. Selection of final models for total botex

After selecting the short list of candidate drivers, we estimated regressions using the general-to-specific approach discussed above (in Section 4.2.2). Essentially, we estimated a model containing the short list of drivers and incrementally excluded those found not to have a statistically significant impact on companies' botex. However, as we discuss above, this approach inherently involves a degree of expert judgement to develop the final models. Hence, while we do impose the following objective set of criteria when selecting models, we also recognise that this process may result in more than one model that meets them. We therefore identify, as we explain below, more than one model that captures differences in companies' botex:

---

63 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. 73.

4. Our models pass the Ramsey RESET test for model specification at the 5% significance level;
5. All coefficient estimates have an intuitive sign and value; and
6. All regressions include several explanatory variables that have a statistically significant impact on costs.

We discuss the final stage of our model development below:

- We run an initial regression using all the short-listed explanatory variables we identify;
- We identify variables with counterintuitive coefficients, and assess if the model may exhibit multicollinearity that explains the counterintuitive results. The treatment of highly correlated explanatory variables requires a high degree of expert judgement. We discuss a few specific examples briefly below:
  - For instance, we find counterintuitive results if we include both the share of water treated at level 5 complexity or above and the share of surface water in treated water, which are highly correlated and control for similar drivers of water companies' costs. This suggests that it may not be appropriate to include both drivers simultaneously in a regression model. We therefore develop models that include either the share of water treated at level 5 and above (see Models 1 and 3 in Table 4.2 below), or the share of surface water as a cost driver (see Model 2), but not both.
  - We only include one variable that controls for the age of the network, the share of mains installed pre-1940. Our Monte Carlo analysis suggests that, out of the network age variables provided in the dataset, this variable leads to models with the best statistical outcomes. Including more than one network age variable leads to counterintuitive coefficient estimates (due to potential issues around multicollinearity). We have therefore only included the share of pre-1940 mains as a cost driver in our three models. We find that this cost driver is statistically significant in all three models at the 1% level (see Table 4.2), and the coefficient has an intuitive sign, implying that older networks cause higher botex.
- We remove any explanatory variables with counterintuitive coefficients from our models. For instance, the coefficient on the logarithm of the number of sources per unit of input was negative (but not statistically significant) in some model specifications, so we removed this driver from those models.[64]
- We do not necessarily remove variables from our models if they are found to have a statistically insignificant impact on costs, if the estimated sign (and scale) of the relationship is intuitive and we have strong economic or technical reasons to believe it is an important driver of costs. For instance, we do not remove 'log raw mains over DI' from Model 1, because we consider it an important driver of costs based on economic logic. We also include 'log average pumping head' in all our models. Coefficients estimates for 'log average pumping head' are not statistically significant in any of our

[64] This is counterintuitive because we understand that water from boreholes is typically cheaper to abstract and treat than surface water.

models, but the estimated coefficient has the intuitive sign, and the coefficient estimate is also fairly stable across the models.

Table 4.2 below presents our final three models for total botex. We developed multiple models, as opposed to a single model, because the process described above does not lead to a single "correct" model for the purpose of benchmarking costs. Developing multiple models also allowed us to better account for multicollinearity issues. For instance, the structure of companies' water sources, water quality and water treatment complexity is accounted for in the various models through different explanatory variables:

1. In Model 1, the share of water treated at WTWs of complexity level 5 and above is the only variable that controls for this factor;
2. In Model 2, we control for this factor by including the share of surface water (in treated water) and the reservoir share of DI as explanatory variables; and
3. In Model 3, we include the reservoir share variable in addition to the level 5 treatment complexity variable.

We included between 7 and 8 cost drivers in each model (in addition to the annual dummy variables that we do not present in Table 4.2). All 3 of our final models pass the Ramsey RESET test for model specification, and all have a high R-squared (of between 63% and 78%), implying that variation in the explanatory variables explains a higher share of the variation in botex unit costs than the CMA's PR14 models.[65] The majority of cost drivers have coefficients that are statistically significant in each of the three models.

[65] The maximum adjusted R-squared of the CMA's models developed for Bristol Water's PR14 appeal was 43:

CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. A4(2)-51.

Privileged and Confidential

Table 4.2
Total Botex Models– Regression Results

VARIABLES	Model 1	Model 2	Model 3
ln_dist_input_per_prop	0.610	0.774**	0.719*
ln_mains_per_prop	0.400*	0.217	0.499***
ln_raw_mains_over_input	0.0427		
share_water_treated_l5	0.454***		0.277*
share_pre1940_mains	0.648**	1.007***	0.611**
relined_renewed_share	19.64*	37.97***	23.18**
ln_avg_pump_head_agg	0.103	0.0710	0.0746
share_surfacewat_treated		0.677***	
reservoir_share		0.0857	0.236*
ln_sources_over_input		0.211**	
Constant	-3.688***	-3.033***	-3.812***
Observations	64	64	64
R-squared	0.631	0.778	0.678
Ramsey RESET test p-value	0.45 ✓	0.07 ✓	0.28 ✓

*Note: Our models also include time dummy variables; *** p<0.01, ** p<0.05, * p<0.1*

4.3.4. Controlling for Bristol Water's company-specific characteristics in our models

In addition to developing statistically robust models, the cost drivers in these models also control for Bristol Water's company-specific characteristics that influence its costs.

For instance, while it may be possible to develop statistically robust models that do not control for differences in the level of companies' water treatment complexity, such models would not produce robust results in the case of Bristol Water, because Bristol Water is an outlier relative to its comparators in that it treats the majority of its water at a very high complexity. To the extent possible, we have attempted to control for this and other differentiating characteristics of Bristol Water by including cost drivers in our econometric models that capture them:

- *Reservoir share (and river share, borehole share)*: Bristol Water's structure of water sources means that it gets relatively low quality water that is expensive to treat and costly to abstract;
- *Share of water treated at complexity level 5 and above*: Bristol Water treats its water at a high complexity, due to the low quality of its water sources. Bristol Water is an outlier especially in the share of water it treats in water treatment works of complexity level 5 (ie. through very complex treatment processes);
- *Share of mains renewed and relined*: Bristol Water had a large mains renewal and relining programme in place during AMP5. This programme (and the high share of mains Bristol Water renewed or relined) is a key driver of Bristol Water's relatively high capital maintenance costs during the 2012-2015 period; and

- *Age of mains (eg. the share of mains installed pre-1940)*: Bristol Water has a relatively old network, which we would expect to increase the frequency of pipe bursts.

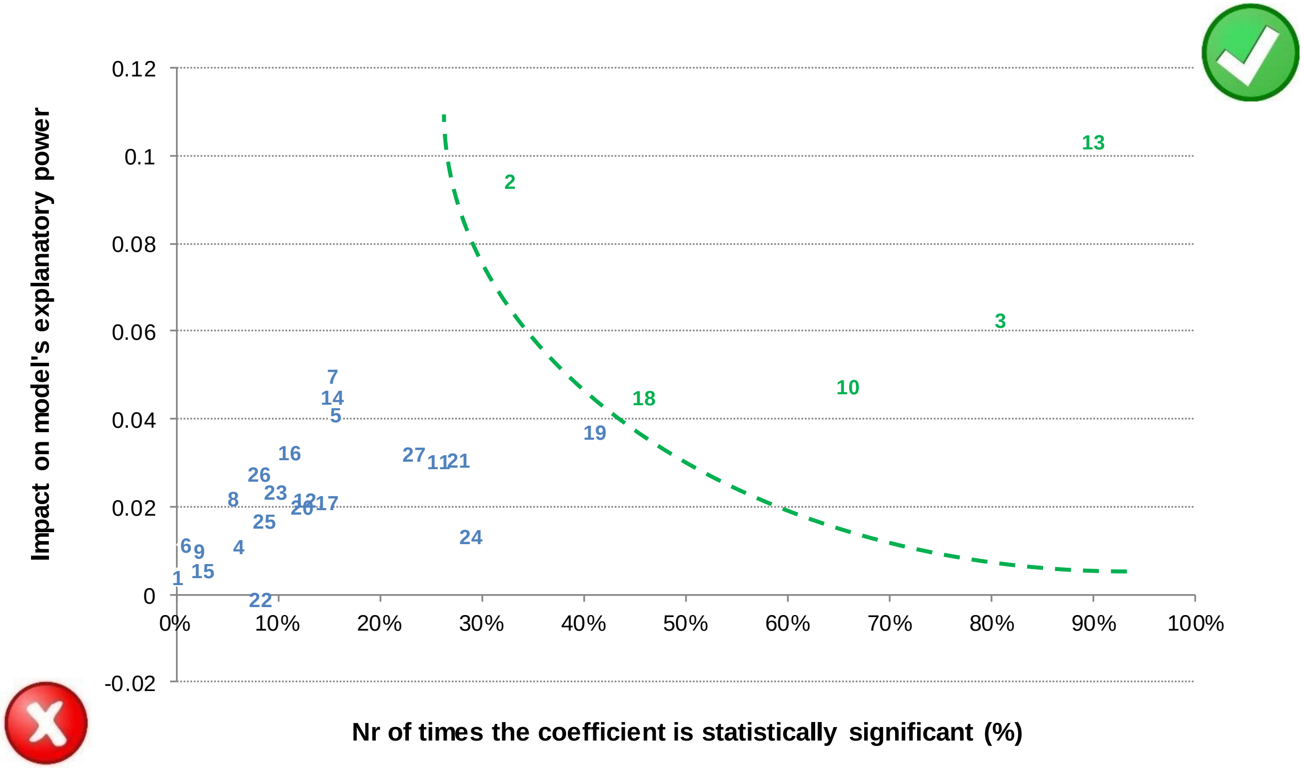
We discuss Bristol Water's key differentiating characteristics in more detail, and provide evidence that Bristol Water is an outlier in the above cost drivers, in our separate report on special cost factors.

4.4. Developing Network+ Models

4.4.1. Monte Carlo analysis for network+

We present the results of our Monte Carlo analysis for network+ in Figure 4.3 and Figure 4.4 below. These figures are in the same format as the figures summarising the results of our Monte Carlo analysis for total botex.

Figure 4.3
Assessment of Candidate Explanatory Variables – Network+



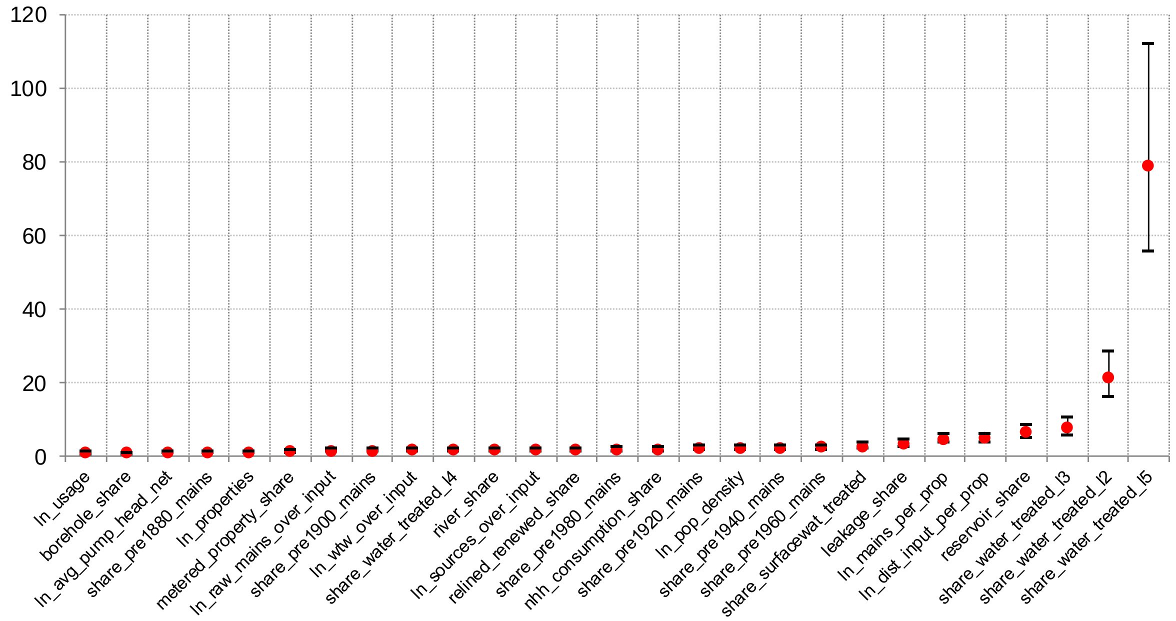
Driver Description

1 Ln (connected properties)
2 **Ln (length of mains/ connected properties)**
3 **Ln (DI/ connected properties)**
4 Ln (water delivered/ connected properties)
5 Ln (population/ connected properties)
6 Ln (average pumping head network+)
7 Ln (nr of sources/ DI)
8 Ln (water treatment works/ DI)
9 Ln (length of raw mains and conveyors/ DI)
10 **Water treated at level 2 or above**
11 Water treated at level 3 or above
12 Water treated at level 4 or above
13 **Water treated at level 5 or above**
14 Surface water treated/ Total water treated
15 Length of mains pre-1880/ Total length of mains
16 Length of mains pre-1900/ Total length of mains
17 Length of mains pre-1920/ Total length of mains
18 **Length of mains pre-1940/ Total length of mains**
19 Length of mains pre-1960/ Total length of mains
20 Length of mains pre-1980/ Total length of mains
21 Length of renewed and relined mains/ Total length of mains
22 Proportion of water from boreholes
23 Proportion of water from rivers
24 Proportion of water from reservoirs
25 Water delivered to non-households/ Total water delivered
26 Metered properties/ Total nr of properties
27 Leakage/ Distribution input

Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

Privileged and Confidential

Figure 4.4
Assessment of Candidate Explanatory Variables – Network+
Odds Ratios of Models Passing Selection Criteria, from the Inclusion of the Given Driver



Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.4.2. Short list of candidate cost drivers for our network+ models

The Monte Carlo analysis for network+ suggests that the same drivers are relevant for network+, as for total botex. Given that network+ costs account for over 85% of total botex costs, this result is in line with expectations. We therefore include the same cost drivers in our short list of explanatory variables for network+, as in our short list for total botex.

4.4.3. Selection of final models for network+

We follow the same approach to developing our final models for network+ as we have done for our total botex models (discussed in Section 4.3.3). However, our models for network+ are slightly different from our total botex models:

- We drop the 'log of raw mains and conveyors over DI cost driver', because we find that this cost driver is not statistically significant, and often takes a negative value. The likely explanation for this may be that raw water transport costs, which are the only value chain element within network+ affected by this cost driver, constitute a very small share of total network+ costs.

- Unlike our total botex models, we do not include the 'log average pumping head' variable in all three network+ models,[66] because we find a counterintuitive (ie. negative) coefficient under some model specifications.
- Similar to our model development for total botex, we include the 'share of water treated at WTWs of complexity level 5 (and above)' in two of our models, and we include the share of surface water (within total treated water) in a third model specification. We have not included both these cost drivers simultaneously in any model, due to multicollinearity.
- Model 1, Model 2 and Model 3 in Table 4.3 below are very similar to the corresponding models developed for total botex (see Table 4.2). Specifically:
  - Model 1: The model for network+ excludes the logarithm of raw mains and conveyors over DI as a cost driver and the logarithm of average pumping head as cost drivers, which differs from Model 1 for total botex;
  - Model 2: The network+ model excludes log average pumping head and reservoir share as cost drivers, which differs from Model 2 for total botex;
  - Model 3: Includes the same explanatory variables as Model 3 for total botex.[67]

Table 4.3
Network+ Models Developed for Bristol Water – Regression Results

VARIABLES	Model 1	Model 2	Model 3
ln_dist_input_per_prop	0.826**	0.943***	0.977**
ln_mains_per_prop	0.584***	0.453	0.570***
share_water_treated_l5	0.304*		0.222
share_pre1940_mains	0.865***	1.239***	0.771**
relined_renewed_share	20.59*	37.64**	22.19*
ln_avg_pump_head_net			0.0634
share_surfacewat_treated		0.530**	
reservoir_share			0.175
ln_sources_over_input		0.121	
Constant	-3.710***	-3.452***	-3.908***
Observations	64	64	64
R-squared	0.601	0.712	0.641
Ramsey RESET test p-value	0.61 ✓	0.07 ✓	0.46 ✓

*Note: Our models also include time dummy variables; *** p<0.01, ** p<0.05, * p<0.1*

66 For network+, we use a version of the average pumping head variable that is specific to the value chain elements within network+ (ie. we use the sum of average pumping head across raw water transport, water treatment, and treated water distribution).

67 The only difference is that a different measure is used for the average pumping head variable, as explained in the footnote above.

All three of our models are statistically robust, in the sense that they all pass the Ramsey RESET test for model specification, and the majority of cost drivers are statistically significant in all models. We also estimate intuitive coefficients for all cost drivers in all three of our models. We discuss the results of these regression models for Bristol Water's estimated efficient level of costs in Section 4.7.

4.5. Developing Water Resources Models

4.5.1. Monte Carlo analysis for water resources

We present the results of our Monte Carlo analysis for water resources in Figure 4.5 and Figure 4.6 below. These figures are in the same format as the figures summarising the results of our Monte Carlo analysis for total botex and network+.

4.5.2. Short list of candidate cost drivers for our water resources models

Based on the results of our Monte Carlo analysis, we short-list the following variables for inclusion in our water resources models:

- Reservoir share, river share, and borehole share variables;
- Logarithm of sources over DI;
- The share of surface water within treated water; and
- The logarithm of the length of raw mains and conveyors over DI;

In addition to these variables that seem to improve the statistical properties of our models (based on the results of our Monte Carlo analysis), we have also included the logarithm of average pumping head as a cost driver, because we considered that there were strong economic arguments for including this variable in our assessment.[68]

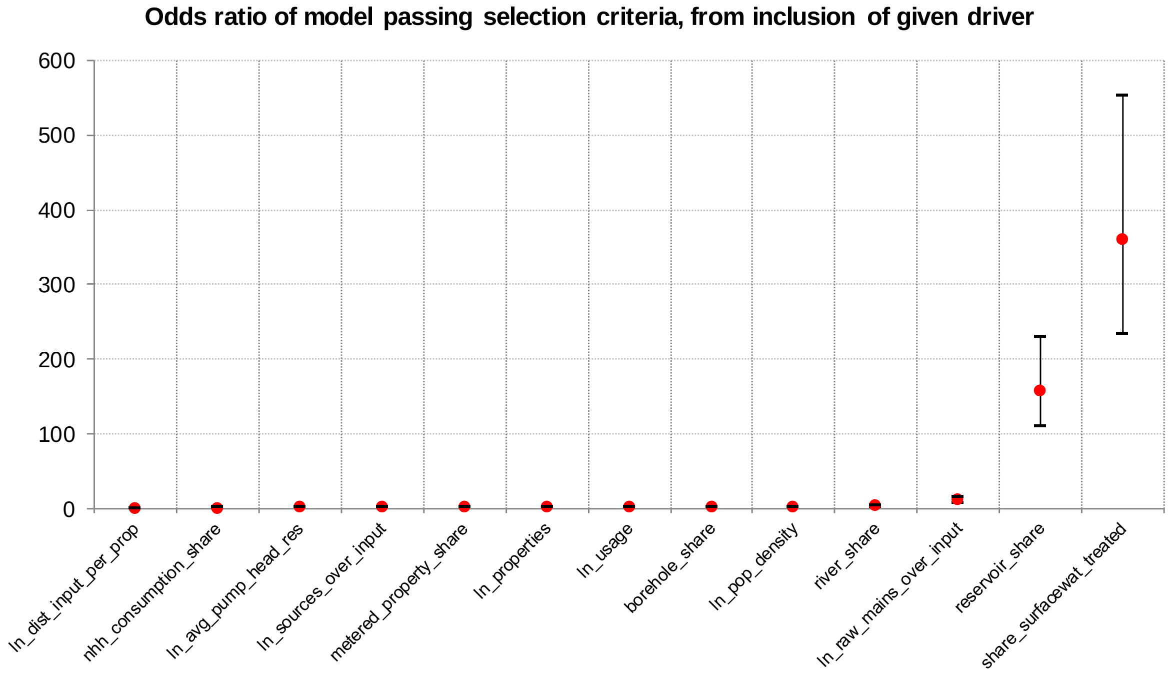
[68] The average pumping head variable we use for our water resources models is specific to the average pumping head within the water resources value chain element, ie. different from the network+ and total botex average pumping head variables.

Privileged and Confidential

Figure 4.5
Assessment of Candidate Explanatory Variables – Water Resources

Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

Figure 4.6
Assessment of Candidate Explanatory Variables – Water Resources
Odds Ratios of Models Passing Selection Criteria, from the Inclusion of the Given Driver



Source: NERA analysis of data in Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.5.3. Selection of final models for water resources

We follow the same approach to developing our final models for water resources, as we did in our model development for total botex and network+ (see Sections 4.3.3 and 4.4.3). We present our final models in Table 4.4 below. We have made the following methodological choices in developing our models:

- We have not developed any models with the share of surface water (within treated water) as a cost driver, due to multicollinearity between this variable and the various water source drivers (such as reservoir share, river share, and borehole share). Specifically, the sum of the river share and reservoir share variables (as a share of DI) is very close to the share of surface water treated variable, which causes multicollinearity. We have also found that models which include the share of surface water as a cost driver typically fail the Ramsey RESET test for model specification, and have therefore not included the share of surface water as a cost driver in our water resources models.
- We attempted to develop models for water resources in which we control for the structure of companies' water sources based on the reservoir share, river share and borehole share variables. Because these variables sum to 1, we could include at most two of these explanatory variables in any one model. We included the reservoir share and borehole share drivers in most models, and did not include river share as a cost driver, because we

found that the river share driver was mostly not statistically significant and was often estimated to have a counterintuitive (ie. negative) impact on costs.[69]

- We included the logarithm of average pumping head as a cost driver in Models 2 and 3. While we did not find that the average pumping head had a statistically significant impact on costs, we considered it appropriate to include this cost driver in these two models, because we found the direction and size of the estimated impact of average pumping head on costs to be intuitive, and there are strong technical reasons to believe it is an important cost driver.

Table 4.4
Water Resources Models Developed for Bristol Water – Regression Results

VARIABLES	Model 1	Model 2	Model 3
ln_raw_mains_over_input		0.0902	0.143**
reservoir_share	0.897***	0.889***	0.790***
ln_sources_over_input	0.203**	0.152**	0.0589
borehole_share	-0.164***	-0.132***	
ln_avg_pump_head_res		0.103	0.107
Constant	-4.043***	-4.437***	-4.607***
Observations	64	64	64
R-squared	0.549	0.604	0.537
Ramsey RESET test p-value	0.08 ✓	0.05 ✓	0.18 ✓

*Note: Our models also include time dummy variables; *** p<0.01, ** p<0.05, * p<0.1*

All three of our models for water resources are statistically robust, and meet our final selection criteria: (1) all models pass the Ramsey RESET test for model specification at the 5% significance level; (2) all coefficient estimates have an intuitive sign and value; and (3) all three models include multiple cost drivers that we find have a statistically significant impact on costs.

4.6. Developing Models for more Disaggregated Cost Categories

As explained in Section 4.1.1, we attempted to develop models for various levels of cost aggregation, including for more aggregated cost categories such as total botex and network+, and relatively more disaggregated cost categories such as water resources, raw water transport, water treatment, and treated water distribution.

In Sections 4.3 to 4.5 above, we discuss our model development for total botex, network+ and water resources. However, we also ran our Monte Carlo analysis separately for raw water transport, water treatment, and treated water distribution costs, to identify a short list of variables to consider including in the final models for each of these value chain elements.

69 We understand that water from boreholes is less expensive to treat than surface water source, so we would expect the coefficient of the river share variable to be positive.

However, we found that there are technical difficulties in developing econometrically robust models at this level of cost disaggregation. For instance, we could not develop a robust model for water transport costs, because the majority of models failed the Ramsey RESET test for model specification and even models that passed the RESET test were not robust, for instance because we estimated counterintuitive (and statistically significant) relationships between some cost drivers and costs.[70]

Therefore, we did not develop any final models for raw water transport, water treatment, and treated water distribution costs. We note that some of the difficulties we experienced in developing robust models for these more disaggregated cost categories may be due to data issues, or inconsistencies across water companies' regulatory reporting practices.[71] However, as companies and Ofwat further review and finalise the dataset, it may become possible to develop robust benchmarking models for these more disaggregated cost categories.

4.7. Assessing Bristol Water's Efficiency

4.7.1. Efficiency results based on individual models

When using econometric benchmarking regressions to estimate companies' efficiency gaps, we need to form an assumption on the level of efficiency score at which we consider a company to be "efficient". For this analysis, we set the upper-quartile level of efficiency as the efficiency standard. This is consistent with the approach used by Ofwat at PR14 and by Ofgem at the RIIO-ED1 price control.[72]

Table 4.5 below shows Bristol Water's efficient costs in water resources, network+, and total botex, based on the models we developed as explained in sections 4.3 to 4.5 above. In addition to presenting the results of the 9 individual models we developed, we also combine the results of our three models for each value chain element.[73]

Our models suggest that Bristol Water is substantially more efficient in network+ than water resources: we estimate an efficiency gap of 12% for Bristol Water in network+ (over the 2014 to 2017 period), compared to an efficiency gap of 45% for water resources. Bristol

---

70 For instance, we estimate statistically significant and negative coefficients for (the logarithm of) the number of water treatment works over DI and for (the logarithm of) the number of water sources over DI.

71 For instance, if companies had a slightly different understanding of the exact boundaries between the raw water transport and water treatment value chain elements, this would distort the results of our disaggregated modelling.

72 CMA (October 2015), "*Bristol Water plc – A reference under section 12(3)(a) of the Water Industry Act 1991: Report*", p. 86.

Ofgem (November 2014), "*RIIO-ED1: Final determination for the slow-track electricity distribution companies – Business plan expenditure assessment",* p. 6.

Other regulators have used less stringent efficiency targets than the upper quartile. For instance, the CMA used an industry-average efficiency target at Bristol Water's PR14 appeal. The UR used the fourth-placed company (out of 15 companies) as the efficiency standard in its recent RP6 price review for NIE (which is an approximation of upper-quartile efficiency, as the UQ company would be the 3.75th placed company). See CEPA/UR (March 2017), "*RP6 Efficiency Advice – The Northern Ireland Utility Regulator",* p.39.

73 We combine our results by averaging modelled costs across the 3 models (for water resources, for instance), and then applying the upper quartile adjustment to these combined modelled costs. We do not take the simple average of efficiency gaps reported.

Water is ranked 15th in our water resources models, which suggest it is the second least efficient company. By contrast, Bristol Water is ranked 10th in our network+ and total botex models.

As Table 4.5 shows, we find that Bristol Water is more efficient in total botex than in either network+ or water resources. This may arise because of trade-offs between the various cost categories, which lead the results of individual models to be misleading as a guide to the overall efficiency of any one company.[74]

Table 4.5
Efficiency Results for Bristol Water Based on NERA's Model Development[75]

Model		Average Smoothed Annual Costs (2013/14 to 2016/17): *Modelled Cost, Pre-UQ Adjustment*	*Actual*	*Delta*	Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap: *£*	*%*	*Rank*	*Model Passes RESET test?*
Water Resources	1	11.36	14.53	3.17	10.43	4.10	39%	15	✓
	2	10.93	14.53	3.59	9.79	4.74	48%	15	✓
	3	10.48	14.53	4.05	9.44	5.09	54%	15	✓
	Combined	10.92	14.53	3.61	9.99	4.54	45%	15	
Network+	1	64.23	68.64	4.41	60.51	8.13	13%	12	✓
	2	66.84	68.64	1.80	60.77	7.86	13%	9	✓
	3	66.41	68.64	2.23	62.55	6.09	10%	10	✓
	Combined	65.82	68.64	2.81	61.14	7.49	12%	10	
Total Botex	1	78.64	83.16	4.52	73.82	9.34	13%	11	✓
	2	79.72	83.16	3.44	75.77	7.40	10%	11	✓
	3	79.69	83.16	3.48	74.88	8.28	11%	10	✓
	Combined	79.35	83.16	3.81	74.93	8.23	11%	10	

Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.7.2. Aggregate efficiency results

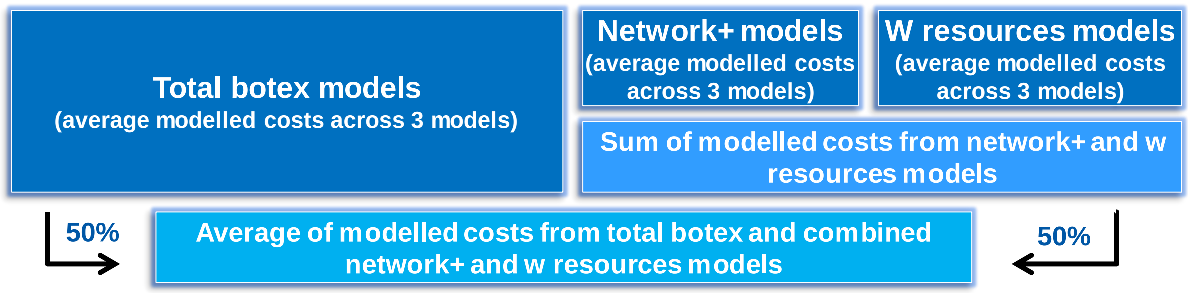
We combine the results of our various models to provide a single estimate of Bristol Water's efficient costs, following the process explained in Figure 4.7. First we sum modelled costs across the combined network+ and water resources models. We then take the simple average

[74] In fact, it would be incorrect to set cost allowances based on the upper quartile level of costs (as calculated separately) for individual cost categories. Estimating efficient costs separately for individual categories of costs would identify different companies as UQ efficient for the individual cost categories, and therefore the total efficient cost estimate (determined as the sum of efficient costs across all cost categories) could be lower than the theoretical efficient frontier. In other words, the efficient cost estimates arising from such a benchmarking methodology (sometimes referred to as "partial benchmarking") may be lower than the total actual costs of the most efficient company.

[75] We have also estimated the efficiency gaps and rankings for the other water companies, based on our own models. We present these results, in summary form, in Section 4.7.4.

of (1) modelled costs from this "bottom-up" approach and (2) modelled costs from our combined total botex model, implicitly taking an unweighted average of the two approaches. We then apply an upper-quartile adjustment to estimate efficient costs for all companies.

Figure 4.7
Our Approach to Combining the Results of the Various Models



By combining the results of our 9 models, we estimate an efficiency gap of 13% for Bristol Water in total botex over the 2014 to 2017 period (see Table 4.5 below).

Table 4.6
Aggregate Efficiency Results for Bristol Water

Model	Average Smoothed Annual Costs (2013/14 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap		
	Modelled Cost, Pre-UQ Adjustment	*Actual*	*Delta*		*£*	*%*	*Rank*
Aggregate Results	78.05	83.16	5.12	73.71	9.46	13%	12

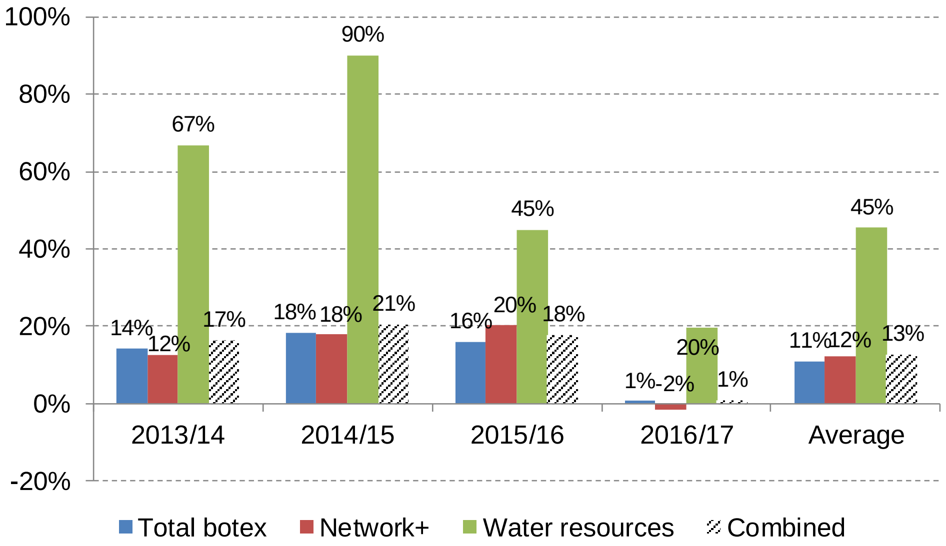
Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.7.3. Annual efficiency results

We also estimate Bristol Water's efficiency gaps separately for each year of our analysis. We find that Bristol Water's efficiency gap has been falling over time, as Bristol Water has reduced its annual capital maintenance spend during AMP6. By 2016/17, our modelling identifies an efficiency gap for Bristol Water of only 1% in total botex.

Privileged and Confidential

Figure 4.8
Bristol Water's Efficiency Gap Falls Over Time
Annual Efficiency Gaps 2013/14 to 2016/17



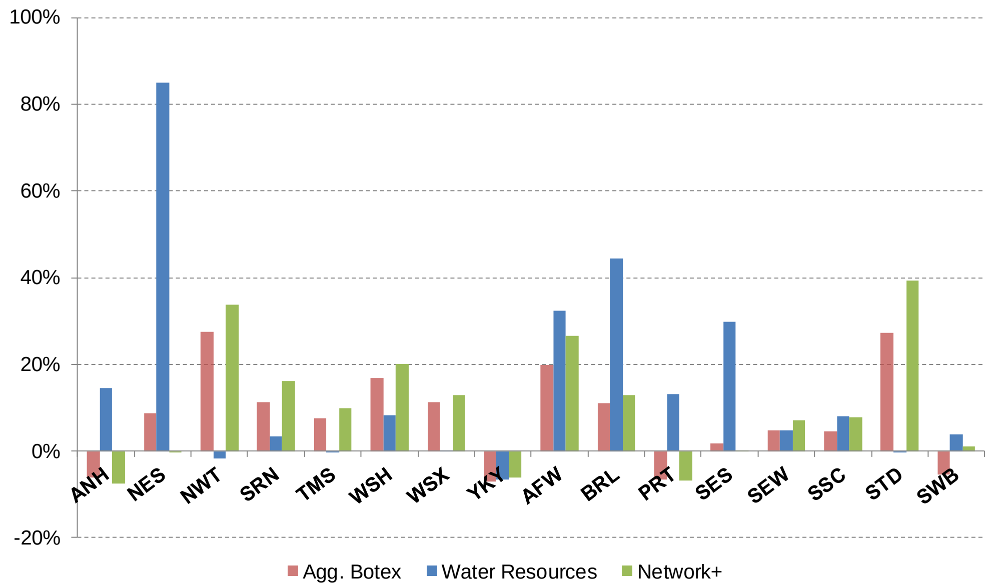
Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

Therefore, the average efficiency gap figures (reported over the 2013/14 – 2016/17 period as a whole) underestimate Bristol Water's current level of efficiency. In fact, even the annual figures reported may underestimate Bristol Water's efficiency in a given year, because we smooth capital maintenance expenditure over a three year period. Hence, we calculate smoothed botex for 2015/16 as opex in 2015/16 plus the average of capital maintenance spend from 2013/14 to 2015/16. Essentially, the modelled efficiency gap in 2016/17 reflects average capital maintenance expenditure over two years of relatively high capital maintenance spend and one year of relatively low capital maintenance spend. On this basis, our analysis suggests that Bristol Water may have achieved costs below the upper quartile efficient company in 2016/17.

4.7.4. Results for other water companies

We have also estimated modelled costs, efficient costs, and efficiency rankings for all of Bristol Water's comparator companies in England and Wales (ie. the E&W WOCs and WASCs). We present companies' efficiency gaps in Figure 4.9, and companies' efficiency ranking in Table 4.7 below.

Figure 4.9
Companies' Efficiency Performance Varies According to Value Chain Element
(4-year efficiency gaps, 2013/14 to 2016/17)



Source: NERA Analysis of Ofwat data.

Table 4.7
Companies' Efficiency Ranking by Value Chain Element in NERA's models[76]

Company	Aggregate Botex	Water Resources	Network+
ANH	3	12	1
NES	9	16	4
NWT	16	2	15
SRN	11	6	12
TMS	8	3	9
WSH	13	10	13
WSX	12	5	11
YKY	1	1	3
AFW	14	14	14
BRL	10	15	10
PRT	2	11	2
SES	5	13	5
SEW	7	8	7
SSC	6	9	8
STD	15	4	16
SWB	4	7	6

Source: NERA Analysis of Ofwat data.

76 We discuss our abbreviations for company names in Appendix D.

Privileged and Confidential

4.8. Sensitivity Analysis

4.8.1. Sensitivity using updated data from Ofwat

As discussed in Section 3, we have used the September version of Ofwat's six-year 2016/17 dataset for the analysis presented throughout this report. We understand however that Ofwat has been going through a data review and cleaning process with the water companies, to ensure that companies report cost and driver data consistently, and to identify and correct errors in the data. Ofwat has released updated versions of the six-year dataset since September, and is expected to release additional versions of the dataset, as companies submit revised / corrected data and as additional data errors are rectified.

We have re-run our 9 regressions (for water resources, network+ and aggregate botex), using a more recent version of Ofwat's six-year dataset, released on 13 October 2017.[77] We find that all our models pass our selection criteria: (1) all models pass the Ramsey RESET test for model specification at the 5% significance level; (2) all coefficient estimates have an intuitive sign and value; and (3) all our models include multiple cost drivers that we find have a statistically significant impact on costs. Given that the revisions to the dataset were very minor, the efficiency results based on the updated dataset remain practically unchanged, relative to the results presented in Section 4.7 above. In our combined aggregate results for botex, we estimate an efficiency gap of 12% for Bristol Water (down from 13% using the original data). However, Bristol Water is still ranked the twelfth most efficient company when combining the results of our 9 models (see Table 4.8 below).

Table 4.8
Efficiency Results for Bristol Water Based on Updated Ofwat Data

Model		Average Smoothed Annual Costs (2013/14 to 2016/17) *Modelled Cost, Pre-UQ Adjustment*	*Actual*	*Delta*	Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap *£*	*%*	*Rank*	*Model Passes RESET test?*
Water Resources	1	11.35	14.53	3.18	10.45	4.08	39%	15	✓
	2	10.93	14.53	3.60	9.79	4.74	48%	15	✓
	3	10.48	14.53	4.05	9.44	5.08	54%	15	✓
	Combined	10.92	14.53	3.61	9.99	4.54	45%	15	
Network+	1	64.54	68.64	4.10	60.86	7.77	13%	12	✓
	2	67.03	68.64	1.61	61.28	7.36	12%	9	✓
	3	66.53	68.64	2.10	62.51	6.12	10%	10	✓
	Combined	66.03	68.64	2.60	61.08	7.56	12%	10	
Total Botex	1	78.88	83.16	4.29	74.28	8.88	12%	11	✓
	2	79.86	83.16	3.31	75.49	7.67	10%	11	✓
	3	79.84	83.16	3.32	74.85	8.31	11%	11	✓
	Combined	79.53	83.16	3.64	74.93	8.23	11%	10	
Aggregate Results		78.24	83.16	4.92	74.24	8.92	12%	12	

Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

77 We note that the differences between the two versions of the dataset were very minor: the most important changes affected the network age variables of Anglian Water and United Utilities.

4.8.2. Sensitivity using a 17-company dataset

As explained in Section 3.1, we have accounted for the recent mergers of Severn Trent Water with Dee Valley Water, and of Bournemouth Water with South West Water in our analysis. In other words, we have conducted our analysis with a 16-company dataset, both in our update of existing benchmarking models and in our own model development.

We understand from our discussions with Bristol Water that Ofwat is considering using a dataset of 17 or 18 companies instead of a 16-company dataset, which would account for both of the recent mergers in the E&W water industry. Given Ofwat's preference that Severn Trent Water and Dee Valley Water provide separate data tables, we have run a sensitivity analysis based on a 17-company dataset (by only accounting for the Bournemouth-South West Water merger). Specifically, we have re-run our 9 models using the 17-company dataset. We have found that our regression results change slightly from the move from an analysis based on 16 companies to an analysis based on 17 companies:

- All our models continue to pass the Ramsey RESET test for model specification, and all our models include multiple cost drivers that have a statistically significant impact on costs. However, using the 17-company dataset, we estimate a negative coefficient for the average pumping head variable in all our models (in which this cost driver is included). While this does suggest a counterintuitive relationship between costs and drivers, we note that the negative coefficient is not statistically significant in any of our models. We understand that there may still be data issues with the average pumping head variable in Ofwat's six-year dataset, and that Ofwat is working with the water companies to ensure that average pumping head data is reported consistently across companies.
- We find that Bristol Water performs marginally worse in our models when we use the 17-company dataset to run our regression models. Specifically, we estimate a combined aggregate efficiency gap of 16% (compared to the 13% gap estimated using the 16-company dataset). Bristol Water is ranked 14th out of the 17 companies in efficiency over the 2013/14-16/17 period (see Table 4.9), a slightly worse performance than in our analysis based on the 16-company dataset (12th out of 16 companies).

Privileged and Confidential

Table 4.9
Efficiency Results for Bristol Water Based on a 17-Company Dataset[78]

Model		Average Smoothed Annual Costs (2013/14 to 2016/17)			Modelled Efficient Costs, Post-UQ Adjustment	Implied Efficiency Gap			Model Passes RESET test?
		Modelled Cost, Pre-UQ Adjustment	*Actual*	*Delta*		*£*	*%*	*Rank*	
Water Resources	1	10.92	14.53	3.61	9.87	4.66	47%	16	✓
	2	10.48	14.53	4.05	9.71	4.82	50%	16	✓
	3	10.16	14.53	4.37	9.14	5.39	59%	16	✓
	Combined	10.52	14.53	4.01	9.95	4.58	46%	16	
Network+	1	62.84	68.64	5.79	58.12	10.52	18%	13	✓
	2	65.66	68.64	2.97	59.65	8.98	15%	10	✓
	3	64.48	68.64	4.16	59.95	8.68	14%	12	✓
	Combined	64.33	68.64	4.31	59.25	9.38	16%	11	
Total Botex	1	75.19	83.16	7.98	70.16	13.00	19%	14	✓
	2	77.73	83.16	5.44	72.89	10.28	14%	14	✓
	3	77.87	83.16	5.30	73.54	9.63	13%	12	✓
	Combined	76.93	83.16	6.24	73.10	10.07	14%	14	
Aggregate Results		75.89	83.16	7.28	71.70	11.46	16%	14	

Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

4.9. Conclusions

As we explain above, we developed our own benchmarking models for Bristol Water based on a rigorous model development process:

1. We made a number of high level methodological choices for developing our models, following regulatory precedent, the CMA's recommendations, and economic intuition;
2. We then identified a long list of candidate cost drivers for inclusion in our models;
3. We used a Monte Carlo tool to help us identify which cost drivers from our long list lead to the most robust models for the industry as a whole; and
4. We developed our final models by selecting drivers to include (from the short list of cost drivers identified using our Monte Carlo tool) based on the general-to-specific approach and our own expert judgement.

We developed 9 models in total: 3 models for total botex, 3 models for network+, and 3 models for water resources. Our models are more robust than any of the Ofwat, CMA or Oxera models, because they pass the Ramsey RESET test for model specification, have a high explanatory power, all coefficients have an economically intuitive sign and magnitude, and the majority of cost drivers included in these models have a statistically significant impact on costs.

[78] We present our detailed regression outputs tables for our sensitivity analyses (both based on the updated dataset and based on a dataset of 17 companies) in Appendix C.

While the primary purpose of our model development has been to create statistically robust models, we also find that these models control for the cost drivers that are most relevant for Bristol Water. Specifically, we estimate an efficiency gap of approximately 13% for Bristol Water over the 2014-2017 period, when we combine the results of all 9 of our benchmarking models. For the latest year (2016/17), we find that Bristol Water is very close to upper quartile efficiency, with an efficiency gap of below 1%, which may understate Bristol Water's efficiency due to our use of smoothed capital maintenance expenditure which Bristol Water has reduced in recent years.

As such, our modelling work shows Bristol Water to be more efficient than the Ofwat, CMA or Oxera models, which are not statistically robust for the reasons set out in Chapter 3.

Privileged and Confidential

5. Conclusion

5.1. Assessing Bristol Water's Relative Efficiency

This report presents the findings of a comparative benchmarking exercise to assess the efficiency of Bristol Water's current costs, using both existing benchmarking models developed for the water industry by Ofwat, the CMA and Oxera, and using benchmarking models we have developed for Bristol Water using Ofwat's 2016/17 six-year dataset. The purpose of this report is to inform the efficiency targets that should be built into Bristol Water's Business Plan submission to Ofwat.

5.2. Existing Benchmarking Models are Not Statistically Robust

We have updated three sets of econometric benchmarking models developed previously within water industry price reviews: (1) Ofwat's models developed for the PR14 price control; (2) the CMA's models developed for the Bristol Water referral at PR14; and (3) Oxera's recent models developed for a group of water companies in preparation for the PR19 review:

- Ofwat's models suggest that Bristol Water is one of the least efficient water companies in England and Wales. Specifically, we estimate an efficiency gap of about 30% for Bristol Water for both botex and totex, suggesting that Bristol Water's actual costs were 30% higher than its upper quartile efficient costs over the 2012-2017 period. However, we conclude that Ofwat's PR14 models are not fit for use at PR19, because there are several economic and technical econometric issues with these models, including those identified by the CMA during the Bristol Water referral.
- The CMA's models, updated using the latest data from Ofwat, produce similar results for Bristol Water as Ofwat's PR14 models, ie. large efficiency gaps for Bristol Water. However, as with the Ofwat PR14 models, we have identified serious statistical robustness problems with the CMA's models, such as counterintuitive coefficient estimates and the failure of these models to pass the Ramsey RESET test, a key test for model specification used by Ofgem at the RIIO-ED1 price review. Further, the CMA itself recommended improvements to its modelling, which it could not implement during the Bristol Water referral due to time and data constraints. Therefore, we conclude that the CMA's models would not have met the CMA's own model selection criteria when estimated using the latest industry data. We therefore conclude that, like the Ofwat PR14 models, they are not fit for use at PR19.
- Oxera developed a number of models for aggregate botex, water resources botex, and network+ botex, reflecting Ofwat's plan for PR19 to set separate binding price controls for wholesale water and network+. Like the Ofwat and the CMA models, Oxera's models also suggest that Bristol Water is one of the least efficient water companies in England and Wales. In water resources, we estimate an efficiency gap for Bristol Water of over 100% (implying that Bristol Water's actual costs were more than double its efficient costs). The estimated efficiency gap in the aggregate botex and network+ models ranges from 15% to 44%, depending on the exact model used. However, we have identified a range of statistical problems with Oxera's models, most likely due to omitted variables, and some models exhibit counterintuitive coefficients. Given these robustness problems

with Oxera's models, we consider they would also need to be developed further before they could be applied at PR19.

5.3. We Have Developed Our Own, Statistically Robust Benchmarking Models for Bristol Water

Given these limitations of existing models, we have developed our own, more statistically robust benchmarking models for Bristol Water based on a rigorous model development process:

1. We first made a number of high level methodological choices for developing our models, following regulatory precedent, the CMA's recommendations, and economic intuition;
2. We then identified a long list of candidate cost drivers for inclusion in our models;
3. We used a Monte Carlo tool to help us identify a short list of the most important cost drivers that lead to the most robust models for the industry as a whole; and
4. We developed our final models by selecting drivers to include from the short list of cost drivers identified using our Monte Carlo tool, based on expert judgement.

Our final models are all more statistically robust than the Ofwat, CMA and Oxera models: they pass key econometric tests for model specification, have a high explanatory power, and the majority of cost drivers included in these models have a statistically significant impact on costs. Further, all coefficients in the final models have an economically intuitive size and sign.

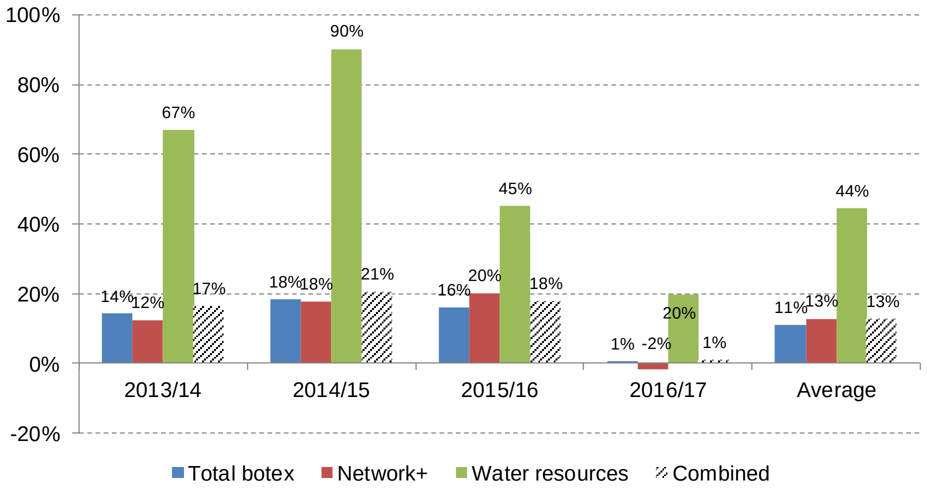
While the primary purpose of our model development has been to create statistically robust models, we have also found that these models control for the cost drivers that are most relevant for Bristol Water. As a result, these models show Bristol Water to be more efficient than the Ofwat, CMA or Oxera models. In particular, our models control for Bristol Water's key differentiating characteristic, its high levels of water treatment complexity.

Figure 5.1 below summarises the results of our own models. We estimate an efficiency gap of 11%, 13% and 44% for Bristol Water, in total botex, network+ botex, and water resources botex respectively. In total, when we combine the results of our 9 final models, we estimate an efficiency gap of 13% for Bristol Water over the 2014-2017 period, suggesting that Bristol Water's actual costs exceeded its efficient level of costs by 13% over this period.[79] However, we find that there is considerable year-on-year variation in Bristol Water's efficiency position. Specifically, Bristol Water has become more efficient, as it has reduced its capital maintenance spend over time: we estimate a combined efficiency gap of below 1% for 2017 (ie. the latest year). Based on our statistically robust models, we conclude that Bristol Water is close to upper quartile efficiency in the last year of our analysis.

[79] We estimate Bristol Water's efficiency over a period of 4 years, because we smooth capital maintenance expenditure over a period of three years (and can therefore only have 4 years of smoothed data to estimate our models, from the six-year Ofwat dataset).

Privileged and Confidential

Figure 5.1
Bristol Water's Efficiency Gap Falls Over Time
Annual Efficiency Gaps 2013/14 to 2016/17



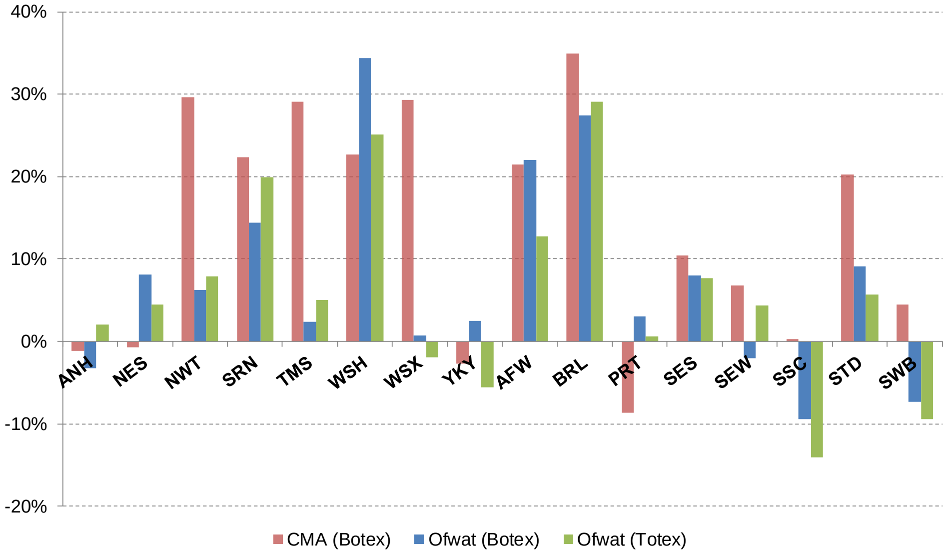
Source: NERA analysis, based on Ofwat's 2016/17 six-year dataset, provided by Bristol Water

Privileged and Confidential

Appendix A. Modelling Results for the Other E&W Water Companies

A.1. Results from Reproducing the PR14 Models

Figure A.1
Companies' Efficiency Performance in the Ofwat and CMA PR14 Models
(6-year efficiency gaps, 2011/12 to 2016/17)



Source: NERA Analysis of Ofwat data.

Table A.1
Companies' Efficiency Ranking in the Ofwat and CMA PR14 models

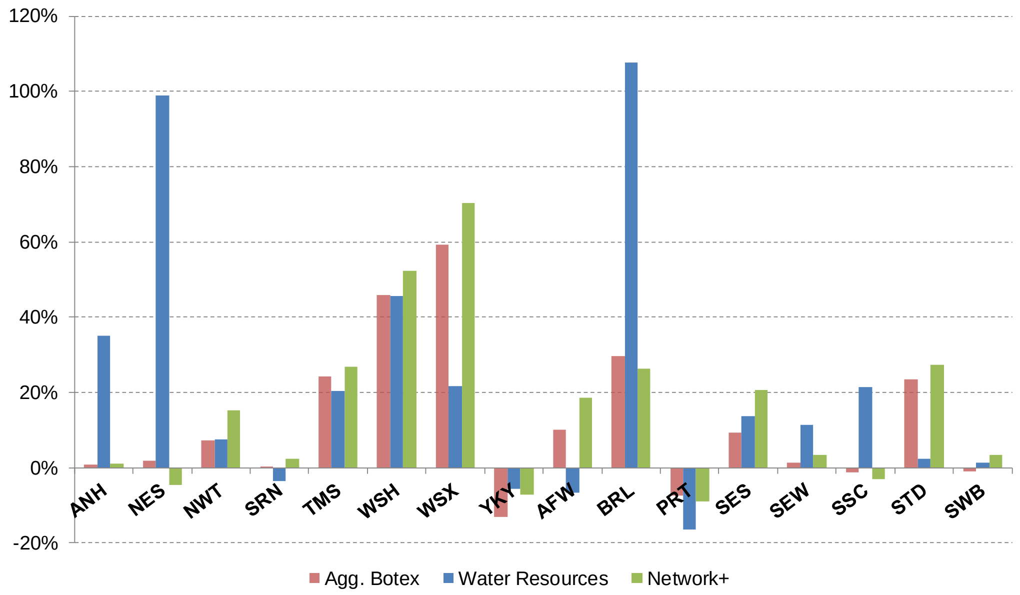
	CMA Unsmoothed botex	CMA Smoothed botex	CMA (Botex)	Ofwat (Botex)	Ofwat (Totex)
ANH	4	2	3	3	6
NES	5	3	4	11	8
NWT	15	13	15	9	12
SRN	11	11	11	13	14
TMS	14	14	13	6	9
WSH	9	12	12	16	15
WSX	13	15	14	5	4
YKY	2	4	2	7	3
AFW	12	10	10	14	13
BRL	16	16	16	15	16
PRT	1	1	1	8	5
SES	8	8	8	10	11
SEW	7	7	7	4	7
SSC	3	5	5	1	1
STD	10	9	9	12	10
SWB	6	6	6	2	2

"Unsmoothed botex" refers to the CMA's three final unsmoothed models, "Smoothed botex" refers to the CMA's four final unsmoothed models, and "CMA (Botex)" reports the efficiency gaps for all seven of the CMA's final models.
Source: NERA Analysis of Ofwat data.

Privileged and Confidential

A.2. Results from Reproducing the Oxera Models

Figure A.2
Companies' Efficiency Performance by Value Chain Element in the Ofwat models
(6-year efficiency gaps, 2011/12 to 2016/17)



Source: NERA Analysis of Ofwat data.

Table A.2
Companies' Efficiency Ranking by Value Chain Element in NERA's Replication of Oxera's Models

Company	Aggregate Botex	Water Resources	Network+
ANH	6	13	5
NES	8	15	3
NWT	9	7	9
SRN	5	4	6
TMS	13	10	13
WSH	15	14	15
WSX	16	12	16
YKY	1	3	2
AFW	11	2	10
BRL	14	16	12
PRT	2	1	1
SES	10	9	11
SEW	7	8	8
SSC	3	11	4
STD	12	6	14
SWB	4	5	7

Source: NERA Analysis of Ofwat data.

Appendix B. Regression Results – Reproducing the Ofwat, CMA, and Oxera models

B.1. Regression Results for Ofwat's PR14 Models

Table B.1
Ofwat's PR14 Models – Regression Results

	Refined totex OLS	Refined totex RE	Refined botex OLS	Refined botex RE
ln_potable_mains	2.768	3.260	1.800	2.413
	(3.79)***	(3.68)***	(2.10)*	(2.61)***
ln_density_mains	-4.395	-3.580	-2.151	-2.772
	(1.05)	(0.87)	(0.43)	(0.64)
ln_mains_sq	0.047	0.040	0.045	0.054
	(0.91)	(0.73)	(0.92)	(0.91)
ln_density_sq	0.970	1.338	0.711	1.109
	(2.67)**	(2.84)***	(1.78)*	(2.25)**
ln_mains_density	1.004	1.141	0.631	0.928
	(3.24)***	(3.99)***	(1.85)*	(2.99)***
ln_pop_density	0.110	-1.491	1.384	-0.368
	(0.12)	(2.92)***	(1.39)	(0.71)
ln_relined_renewed_share	0.004	0.014	0.019	-0.006
	(0.15)	(0.90)	(0.87)	(0.43)
ln_river_share	-0.020	-0.022	-0.013	-0.018
	(1.62)	(2.29)**	(1.14)	(1.82)*
ln_impound_reservoir_share	-0.012	-0.016	-0.001	-0.009
	(1.22)	(1.81)*	(0.13)	(1.08)
time_trend	0.008	0.009	0.015	0.008
	(1.01)	(1.65)*	(1.30)	(1.43)
_cons	-18.996	-18.703	-12.403	-14.680
	(2.85)**	(2.55)**	(1.45)	(1.93)*
R^2	0.98		0.98	
N	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

B.2. Regression Results for the CMA Models

Table B.2
CMA's Linear Unit Cost Models – Regression Results

	EV1, unsmoothed	EV2, unsmoothed (preferred)	EV3, unsmoothed (preferred)	EV1, smoothed	EV2, smoothed (preferred)	EV3, smoothed (preferred)
usage2	0.346	0.336	0.097	0.303	0.296	0.083
	(3.57)***	(3.33)***	(0.69)	(3.29)***	(3.19)***	(0.66)
mains_per_prop	0.003	0.003	0.005	0.003	0.004	0.005
	(2.45)**	(2.20)**	(2.23)**	(2.80)**	(2.70)**	(2.39)**
river_share_wdpp	-0.106	-0.100		-0.107	-0.103	
	(2.66)**	(2.28)**		(2.80)**	(2.47)**	
imp_reservoir_share_wdpp	0.194	0.199		0.180	0.183	
	(2.53)**	(2.55)**		(2.50)**	(2.52)**	
avg_pump_head_wdpp	0.000	0.000	-0.000	0.000	0.000	-0.000
	(1.34)	(1.26)	(0.58)	(1.44)	(1.40)	(0.43)
year13	0.005	0.005	0.002	0.002	0.002	-0.001
	(0.99)	(0.98)	(0.43)	(0.64)	(0.58)	(0.17)
year14	-0.002	-0.003	-0.004	-0.000	-0.000	-0.002
	(0.31)	(0.40)	(0.60)	(0.00)	(0.09)	(0.36)
year15	-0.004	-0.005	-0.009	0.002	0.002	-0.001
	(0.56)	(0.62)	(1.12)	(0.45)	(0.39)	(0.22)
year16	-0.008	-0.009	-0.016	0.011	0.011	0.004
	(1.07)	(1.17)	(1.98)*	(1.74)	(1.66)	(0.50)
year17	0.007	0.006	-0.003	0.011	0.011	0.003
	(0.90)	(0.85)	(0.33)	(1.91)*	(1.81)*	(0.44)
nhh_consumption_share		-0.082	0.041		-0.055	0.038
		(0.66)	(0.26)		(0.50)	(0.24)
share_wat_treated_l4_wdpp			0.117			0.100
			(1.93)*			(1.85)*
_cons	-0.096	-0.077	-0.024	-0.084	-0.071	-0.019
	(1.53)	(1.24)	(0.33)	(1.46)	(1.24)	(0.26)
R^2	0.46	0.47	0.39	0.52	0.52	0.41
N	96	96	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Table B.3
CMA's Logged Unit Cost Models – Regression Results

	EV1, unsmoothed	EV2, unsmoothed (preferred)	EV3, unsmoothed	EV1, smoothed	EV2, smoothed (preferred)	EV3, smoothed (preferred)
ln_usage2	1.455	1.421	0.756	1.236	1.217	0.636
	(3.14)***	(2.96)***	(1.64)	(2.82)**	(2.73)**	(1.51)
ln_mains_per_prop	0.310	0.365	0.487	0.341	0.372	0.480
	(2.03)*	(1.68)	(1.92)*	(2.31)**	(2.00)*	(2.05)*
river_share	-0.326	-0.308		-0.340	-0.329	
	(2.12)*	(1.83)*		(2.34)**	(2.09)*	
impounding_reservoir_share	0.735	0.757		0.667	0.680	
	(2.30)**	(2.28)**		(2.33)**	(2.31)**	
ln_avg_pump_head	0.081	0.072	-0.058	0.088	0.083	-0.035
	(0.96)	(0.87)	(0.62)	(1.14)	(1.11)	(0.40)
year13	0.047	0.045	0.027	0.019	0.018	0.003
	(1.04)	(1.04)	(0.65)	(0.73)	(0.67)	(0.12)
year14	-0.014	-0.019	-0.024	0.005	0.003	-0.001
	(0.29)	(0.39)	(0.49)	(0.19)	(0.10)	(0.05)
year15	-0.036	-0.038	-0.066	0.022	0.021	-0.002
	(0.61)	(0.67)	(1.19)	(0.62)	(0.56)	(0.06)
year16	-0.064	-0.068	-0.128	0.087	0.085	0.033
	(1.11)	(1.21)	(2.15)**	(1.89)*	(1.77)*	(0.59)
year17	0.062	0.057	-0.013	0.094	0.091	0.029
	(1.13)	(1.11)	(0.23)	(2.15)**	(2.00)*	(0.54)
nhh_consumption_share		-0.712	0.683		-0.404	0.680
		(0.61)	(0.58)		(0.41)	(0.57)
share_water_treated_l4			0.512			0.434
			(2.10)*			(2.02)*
_cons	-2.296	-2.246	-3.004	-2.576	-2.548	-3.164
	(4.09)***	(4.13)***	(3.97)***	(5.04)***	(5.15)***	(4.68)***
R^2	0.43	0.44	0.41	0.46	0.46	0.40
N	96	96	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Table B.4
CMA's Logged Aggregate Cost Models – Regression Results

	EV1, unsmoothed	EV2, unsmoothed	EV3, unsmoothed	EV1, smoothed	EV2, smoothed	EV3, smoothed
ln_usage2	1.424	1.370	0.793	1.209	1.174	0.661
	(3.50)***	(3.49)***	(1.77)*	(3.10)***	(3.15)***	(1.59)
ln_potable_mains	1.061	1.069	1.035	1.053	1.058	1.023
	(17.62)***	(17.64)***	(19.71)***	(19.90)***	(19.70)***	(20.88)***
ln_density_mains	0.699	0.619	0.515	0.666	0.614	0.520
	(4.86)***	(3.37)***	(2.20)**	(4.61)***	(3.73)***	(2.33)**
river_share	-0.403	-0.386		-0.406	-0.395	
	(2.72)**	(2.44)**		(2.89)**	(2.69)**	
impounding_reservoir_share	0.618	0.636		0.567	0.578	
	(1.79)*	(1.84)*		(1.80)*	(1.85)*	
ln_avg_pump_head	0.080	0.067	-0.052	0.087	0.078	-0.031
	(1.04)	(0.91)	(0.60)	(1.21)	(1.16)	(0.36)
year13	0.047	0.043	0.029	0.019	0.016	0.004
	(1.07)	(1.08)	(0.71)	(0.81)	(0.74)	(0.18)
year14	-0.014	-0.021	-0.024	0.005	0.001	-0.001
	(0.29)	(0.44)	(0.50)	(0.20)	(0.04)	(0.05)
year15	-0.038	-0.041	-0.064	0.020	0.018	-0.001
	(0.65)	(0.75)	(1.15)	(0.62)	(0.53)	(0.02)
year16	-0.066	-0.071	-0.125	0.085	0.082	0.035
	(1.18)	(1.39)	(1.99)*	(1.89)*	(1.74)	(0.65)
year17	0.060	0.052	-0.011	0.091	0.086	0.031
	(1.13)	(1.11)	(0.17)	(2.19)**	(2.02)*	(0.59)
nhh_consumption_share		-1.062	0.254		-0.697	0.393
		(0.92)	(0.19)		(0.69)	(0.28)
share_water_treated_l4			0.466			0.403
			(1.79)*			(1.76)*
_cons	-2.845	-2.843	-3.205	-3.048	-3.047	-3.298
	(3.41)***	(3.82)***	(4.54)***	(4.08)***	(4.42)***	(5.06)***
R^2	0.96	0.96	0.96	0.97	0.97	0.97
N	96	96	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

B.3. Regression Results for the Oxera Models

Table B.5
Oxera's Aggregate Botex Models – Regression Results

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
ln_properties	1.019		1.045	1.002				0.966
	(19.67)***		(18.53)***	(26.05)***				(23.86)***
share_water_treated_l3	0.349	0.389	0.527	0.377	0.223	0.331	0.114	
	(0.87)	(1.01)	(2.81)**	(1.15)	(0.55)	(0.90)	(0.29)	
ln_avg_pump_head	-0.052	-0.058	-0.059	-0.060	-0.025	0.029	0.058	-0.030
	(0.64)	(0.67)	(0.66)	(0.68)	(0.34)	(0.38)	(0.57)	(0.34)
share_pre1980_mains	0.658	0.607	0.404	0.640	0.568		0.609	
	(1.13)	(1.23)	(0.89)	(1.79)*	(0.96)		(1.04)	
ln_raw_mains_over_input	0.043	0.037			0.111	0.076	0.116	-0.015
	(0.39)	(0.37)			(0.97)	(0.96)	(1.09)	(0.19)
year13	-0.013	-0.013	-0.014	-0.012	-0.017	0.028	0.038	-0.007
	(0.33)	(0.32)	(0.33)	(0.28)	(0.45)	(0.71)	(0.99)	(0.17)
year14	-0.054	-0.054	-0.053	-0.053	-0.061	-0.026	-0.013	-0.052
	(1.04)	(1.05)	(1.02)	(1.02)	(1.21)	(0.51)	(0.27)	(0.97)
year15	-0.098	-0.099	-0.098	-0.097	-0.103	-0.059	-0.040	-0.098
	(1.73)	(1.76)*	(1.71)	(1.71)	(1.88)*	(1.09)	(0.74)	(1.68)
year16	-0.151	-0.152	-0.154	-0.150	-0.154	-0.111	-0.086	-0.159
	(3.05)***	(3.18)***	(2.98)***	(3.07)***	(3.30)***	(2.45)**	(1.90)*	(3.24)***
year17	-0.030	-0.032	-0.036	-0.011	-0.029	0.005	0.038	-0.040
	(0.65)	(0.75)	(0.79)	(0.24)	(0.66)	(0.12)	(0.82)	(0.89)
ln_sources_over_input			0.125					
			(1.18)					
borehole_share				-0.057				
				(2.24)**				
ln_population					1.024			
					(18.89)***			
ln_dist_input						0.985		
						(21.67)***		
ln_water_delivered							1.037	
							(17.41)***	
share_water_treated_l2								0.781
								(2.12)*
_cons	-2.623	-2.465	-2.545	-2.491	-3.399	-1.770	-2.296	-2.409
	(3.88)***	(4.95)***	(3.90)***	(3.47)***	(5.01)***	(2.69)**	(3.04)***	(3.03)***
R^2	0.95	0.26	0.95	0.95	0.95	0.95	0.95	0.95
N	96	96	96	96	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Table B.6
Oxera's Network+ Botex Models – Regression Results

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
ln_properties	1.026		1.040	1.023	1.005	1.046	1.014	1.007			
	(24.51)***		(17.13)***	(17.28)***	(23.29)***	(15.06)***	(16.64)***	(18.66)***			
share_water_treated_l3	0.346	0.390	0.292	0.316				0.382	0.381	0.397	0.290
	(1.00)	(1.08)	(1.08)	(1.07)				(1.24)	(0.99)	(1.07)	(0.73)
ln_avg_pump_head_net	-0.041	-0.047	-0.062	-0.067	-0.015	-0.038	-0.026	-0.014	-0.010	0.039	0.079
	(0.42)	(0.45)	(0.58)	(0.55)	(0.14)	(0.44)	(0.27)	(0.14)	(0.11)	(0.42)	(0.67)
share_pre1980_mains	0.822	0.771	1.027	0.963	0.720	1.052	1.087				
	(1.88)*	(1.71)	(1.86)*	(1.77)*	(1.64)	(2.67)**	(2.70)**				
year13	-0.010	-0.010	-0.009	-0.010	-0.007	-0.009	-0.009	-0.007	-0.010	0.033	0.045
	(0.22)	(0.22)	(0.19)	(0.22)	(0.15)	(0.21)	(0.20)	(0.16)	(0.25)	(0.77)	(1.06)
year14	-0.054	-0.054	-0.050	-0.052	-0.051	-0.050	-0.050	-0.054	-0.062	-0.026	-0.016
	(0.97)	(0.98)	(0.89)	(0.92)	(0.90)	(0.87)	(0.88)	(0.97)	(1.16)	(0.47)	(0.30)
year15	-0.087	-0.087	-0.079	-0.084	-0.084	-0.082	-0.081	-0.089	-0.097	-0.050	-0.036
	(1.42)	(1.44)	(1.31)	(1.35)	(1.34)	(1.30)	(1.27)	(1.47)	(1.63)	(0.83)	(0.60)
year16	-0.149	-0.150	-0.138	-0.144	-0.149	-0.137	-0.135	-0.155	-0.163	-0.113	-0.098
	(2.83)**	(2.91)**	(2.70)**	(2.71)**	(2.81)**	(2.51)**	(2.45)**	(3.08)***	(3.31)***	(2.33)**	(2.06)*
year17	-0.015	-0.018	-0.002	-0.008	-0.013	0.031	0.006	-0.024	-0.032	0.016	0.033
	(0.34)	(0.40)	(0.04)	(0.18)	(0.28)	(0.56)	(0.12)	(0.54)	(0.73)	(0.35)	(0.73)
ln_density_mains			-0.330								
			(1.26)								
ln_density_area				-0.100							
				(0.94)							
share_water_treated_l2					0.582						
					(1.78)*						
borehole_share						-0.080					
						(2.01)*					
share_surfacewat_treated							0.232				
							(1.20)				
ln_mains_per_prop								0.237			
								(0.72)			
ln_population									1.000		
									(28.46)***		
ln_dist_input										0.984	
										(27.74)***	
ln_water_delivered											1.014
											(23.13)***
_cons	-3.025	-2.817	-3.975	-3.116	-3.173	-3.013	-3.034	-3.141	-3.293	-2.071	-2.228
	(3.86)***	(4.76)***	(4.63)***	(3.91)***	(3.89)***	(3.64)***	(3.62)***	(3.99)***	(3.88)***	(2.69)**	(2.59)**
R^2	0.94	0.24	0.95	0.94	0.94	0.94	0.94	0.94	0.93	0.94	0.94
N	96	96	96	96	96	96	96	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Table B.7
Oxera's Water Resources Botex Models – Regression Results

	Model 1	Model 2	Model 3	Model 4
ln_properties	1.007		1.000	0.986
	(13.18)***		(7.86)***	(10.38)***
ln_raw_mains_over_input	0.182	0.183		
	(2.14)**	(2.11)*		
ln_avg_pump_head_res	0.005	0.005	-0.016	-0.016
	(0.04)	(0.04)	(0.15)	(0.14)
year13	-0.026	-0.026	-0.018	-0.019
	(0.64)	(0.65)	(0.41)	(0.43)
year14	-0.025	-0.025	-0.022	-0.021
	(0.45)	(0.45)	(0.39)	(0.36)
year15	-0.138	-0.138	-0.135	-0.132
	(2.65)**	(2.65)**	(2.57)**	(2.46)**
year16	-0.135	-0.135	-0.132	-0.129
	(1.83)*	(1.82)*	(1.77)*	(1.72)
year17	-0.085	-0.084	-0.082	-0.039
	(1.19)	(1.18)	(1.14)	(0.48)
ln_sources_over_input			-0.047	
			(0.37)	
borehole_share				-0.121
				(1.05)
_cons	-4.071	-4.020	-4.206	-3.970
	(4.99)***	(8.69)***	(4.18)***	(4.01)***
R^2	0.89	0.18	0.87	0.88
N	96	96	96	96

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Appendix C. Detailed Regression Results – 'NERA' models

C.1. Regression Results for the NERA Models

Table C.1
Detailed Regression Results for NERA Models – 16 Companies, September Data

	Total Botex			Water Resources			Network Plus		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
ln_dist_input_per_prop	0.610	0.774	0.719				0.826	0.977	0.943
	(1.51)	(2.68)**	(1.98)*				(2.28)**	(2.34)**	(3.34)***
ln_mains_per_prop	0.400	0.217	0.499				0.584	0.570	0.453
	(1.87)*	(1.08)	(3.36)***				(3.26)***	(3.37)***	(1.75)
ln_raw_mains_over_input	0.043				0.090	0.143			
	(0.53)				(1.46)	(2.73)**			
share_water_treated_l5	0.454		0.277				0.304	0.222	
	(3.32)***		(1.75)*				(1.87)*	(1.26)	
share_pre1940_mains	0.648	1.007	0.611				0.865	0.771	1.239
	(2.39)**	(4.11)***	(2.79)**				(3.27)***	(2.78)**	(4.28)***
relined_renewed_share	19.636	37.966	23.178				20.587	22.194	37.643
	(2.09)*	(3.31)***	(2.36)**				(2.06)*	(2.01)*	(2.93)**
ln_avg_pump_head_agg	0.103	0.071	0.075						
	(0.74)	(0.75)	(0.68)						
share_surfacewat_treated		0.677							0.530
		(4.22)***							(2.85)**
reservoir_share		0.086	0.236	0.897	0.889	0.790		0.175	
		(0.73)	(1.91)*	(5.27)***	(4.74)***	(3.66)***		(1.24)	
ln_sources_over_input		0.211		0.203	0.152	0.059			0.121
		(2.65)**		(2.61)**	(2.14)**	(0.86)			(1.06)
borehole_share				-0.164	-0.132				
				(4.83)***	(4.04)***				
ln_avg_pump_head_res					0.103	0.107			
					(1.22)	(1.14)			
ln_avg_pump_head_net								0.063	
								(0.56)	
year15	-0.017	0.014	-0.007	-0.078	-0.077	-0.079	-0.001	0.005	0.023
	(0.69)	(0.41)	(0.27)	(2.68)**	(2.69)**	(2.77)**	(0.03)	(0.17)	(0.65)
year16	0.015	0.083	0.036	-0.025	-0.025	-0.029	0.031	0.043	0.086
	(0.47)	(1.93)*	(1.05)	(0.57)	(0.57)	(0.65)	(0.83)	(1.13)	(1.85)*
year17	0.001	0.071	0.012	-0.024	-0.041	-0.082	0.025	0.029	0.083
	(0.04)	(1.83)*	(0.34)	(0.34)	(0.62)	(1.05)	(0.72)	(0.81)	(2.26)**
_cons	-3.688	-3.033	-3.812	-4.043	-4.437	-4.607	-3.710	-3.908	-3.452
	(4.41)***	(5.31)***	(5.32)***	(28.52)***	(12.35)***	(11.77)***	(6.48)***	(5.74)***	(4.08)***
R^2	0.63	0.78	0.68	0.55	0.60	0.54	0.60	0.64	0.71
N	64	64	64	64	64	64	64	64	64

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Table C.2
Detailed Regression Results for NERA Models Using the October Update of Ofwat’s Six-Year Dataset

	Total Botex			Water Resources			Network Plus		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
ln_dist_input_per_prop	0.583	0.749	0.691				0.794	0.945	0.921
	(1.45)	(2.54)**	(1.89)*				(2.20)**	(2.24)**	(3.19)***
ln_mains_per_prop	0.388	0.212	0.489				0.571	0.558	0.432
	(1.80)*	(1.03)	(3.24)***				(3.14)***	(3.23)***	(1.63)
ln_raw_mains_over_input	0.044				0.090	0.142			
	(0.53)				(1.44)	(2.71)**			
share_water_treated_l5	0.458		0.284				0.315	0.229	
	(3.35)***		(1.79)*				(1.93)*	(1.30)	
share_pre1940_mains	0.626	0.997	0.585				0.837	0.741	1.217
	(2.32)**	(4.04)***	(2.63)**				(3.13)***	(2.62)**	(4.27)***
relined_renewed_share	19.065	37.341	22.561				19.810	21.450	36.743
	(2.05)*	(3.36)***	(2.30)**				(1.98)*	(1.95)*	(2.95)***
ln_avg_pump_head_agg	0.097	0.061	0.069						
	(0.69)	(0.62)	(0.62)						
share_surfacewat_treated		0.683							0.545
		(4.13)***							(2.85)**
reservoir_share		0.080	0.234	0.895	0.887	0.788		0.173	
		(0.67)	(1.87)*	(5.27)***	(4.73)***	(3.65)***		(1.21)	
ln_sources_over_input		0.211		0.202	0.152	0.059			0.128
		(2.57)**		(2.61)**	(2.13)**	(0.85)			(1.11)
borehole_share				-0.163	-0.131				
				(4.84)***	(4.02)***				
ln_avg_pump_head_res					0.102	0.106			
					(1.21)	(1.12)			
ln_avg_pump_head_net								0.057	
								(0.51)	
year15	-0.018	0.012	-0.009	-0.078	-0.077	-0.079	-0.002	0.003	0.022
	(0.78)	(0.38)	(0.33)	(2.68)**	(2.69)**	(2.77)**	(0.09)	(0.11)	(0.64)
year16	0.012	0.080	0.033	-0.025	-0.025	-0.029	0.029	0.040	0.084
	(0.39)	(1.91)*	(0.98)	(0.58)	(0.58)	(0.66)	(0.77)	(1.07)	(1.86)*
year17	-0.001	0.069	0.010	-0.024	-0.041	-0.082	0.023	0.026	0.081
	(0.04)	(1.81)*	(0.27)	(0.35)	(0.62)	(1.06)	(0.65)	(0.73)	(2.26)**
_cons	-3.634	-2.979	-3.763	-4.044	-4.433	-4.603	-3.687	-3.856	-3.392
	(4.31)***	(5.12)***	(5.19)***	(28.59)***	(12.32)***	(11.75)***	(6.40)***	(5.54)***	(3.98)***
R^2	0.62	0.77	0.67	0.55	0.60	0.54	0.59	0.63	0.70
N	64	64	64	64	64	64	64	64	64

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Table C.3
Detailed Regression Results for NERA Models Using a 17 Company Dataset

	Total Botex			Water Resources			Network Plus		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
ln_dist_input_per_prop	0.577	0.755	0.754				0.826	1.014	0.987
	(1.26)	(2.89)**	(2.11)*				(2.07)*	(2.53)**	(3.64)***
ln_mains_per_prop	0.520	0.435	0.554				0.610	0.622	0.484
	(2.63)**	(2.17)**	(3.79)***				(3.21)***	(3.84)***	(1.96)*
ln_raw_mains_over_input	0.026				0.073	0.119			
	(0.29)				(1.16)	(2.20)**			
share_water_treated_l5	0.288		0.142				0.234	0.071	
	(1.64)		(0.88)				(1.41)	(0.39)	
share_pre1940_mains	0.762	1.148	0.683				0.859	0.859	1.223
	(2.84)**	(4.56)***	(3.09)***				(3.03)***	(2.89)**	(4.30)***
relined_renewed_share	19.603	35.316	23.153				19.106	23.263	34.205
	(2.04)*	(2.87)**	(2.35)**				(1.85)*	(2.10)*	(2.79)**
ln_avg_pump_head_agg	-0.043	-0.066	-0.022						
	(0.46)	(1.06)	(0.22)						
year15	-0.013	0.012	-0.003	-0.075	-0.074	-0.075	-0.000	0.010	0.022
	(0.51)	(0.38)	(0.11)	(2.73)**	(2.75)**	(2.81)**	(0.02)	(0.33)	(0.65)
year16	0.006	0.056	0.026	-0.062	-0.063	-0.065	0.019	0.040	0.063
	(0.16)	(1.13)	(0.66)	(1.06)	(1.07)	(1.12)	(0.50)	(0.97)	(1.34)
year17	0.010	0.063	0.017	-0.052	-0.069	-0.102	0.025	0.035	0.073
	(0.29)	(1.59)	(0.44)	(0.72)	(1.05)	(1.37)	(0.75)	(0.94)	(2.06)*
share_surfacewat_treated		0.509							0.478
		(3.25)***							(2.87)**
reservoir_share		0.036	0.276	0.838	0.804	0.732		0.235	
		(0.43)	(2.32)**	(4.96)***	(4.11)***	(3.50)***		(1.76)*	
ln_sources_over_input		0.112		0.180	0.105	0.026			0.099
		(1.20)		(2.64)**	(1.74)	(0.36)			(0.88)
borehole_share				-0.144	-0.108				
				(4.35)***	(3.31)***				
ln_avg_pump_head_res					0.103	0.113			
					(1.19)	(1.23)			
ln_avg_pump_head_net								-0.026	
								(0.27)	
_cons	-3.258	-3.023	-3.426	-4.075	-4.518	-4.688	-3.733	-3.582	-3.496
	(4.16)***	(5.14)***	(5.30)***	(35.34)***	(12.24)***	(11.43)***	(6.09)***	(5.60)***	(4.20)***
R^2	0.55	0.73	0.64	0.49	0.54	0.50	0.55	0.61	0.69
N	68	68	68	68	68	68	68	68	68

*Note: T-values shown in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

Privileged and Confidential

Appendix D. Abbreviations of Water Companies' Names

Table D.1
Company Names and Abbreviations

Abbreviation	Full Company Name
ANH	Anglian Water
NES	Northumbrian Water
NWT	United Utilities
SRN	Southern Water
TMS	Thames Water
WSH	Dŵr Cymru Welsh Water
WSX	Wessex Water
YKY	Yorkshire Water
AFW	Affinity Water
BRL	Bristol Water
PRT	Portsmouth Water
SES	SES Water
SEW	South East Water
SSC	South Staffordshire Water
STD	Severn Trent Water (incorporating Dee Valley Water)
SWB	South West Water (incorporating Bournemouth Water)

Report qualifications/assumptions and limiting conditions

This report is for the exclusive use of the NERA Economic Consulting client named herein. This report is not intended for general circulation or publication, nor is it to be reproduced, quoted or distributed for any purpose without the prior written permission of NERA Economic Consulting. There are no third party beneficiaries with respect to this report, and NERA Economic Consulting does not accept any liability to any third party.

Information furnished by others, upon which all or portions of this report are based, is believed to be reliable but has not been independently verified, unless otherwise expressly indicated. Public information and industry and statistical data are from sources we deem to be reliable; however, we make no representation as to the accuracy or completeness of such information. The findings contained in this report may contain predictions based on current data and historical trends. Any such predictions are subject to inherent risks and uncertainties. NERA Economic Consulting accepts no responsibility for actual results or future events.

The opinions expressed in this report are valid only for the purpose stated herein and as of the date of this report. No obligation is assumed to revise this report to reflect changes, events or conditions, which occur subsequent to the date hereof.

All decisions in connection with the implementation or use of advice or recommendations contained in this report are the sole responsibility of the client. This report does not represent investment advice nor does it provide an opinion regarding the fairness of any transaction to any and all parties.

NERA

ECONOMIC CONSULTING

NERA Economic Consulting
Marble Arch House, 66 Seymour Street
London W1H 5BT
United Kingdom
Tel: 44 20 7659 8500 Fax: 44 20 7659 8501
www.nera.com