Thames Water Submission to the CMA inquiry into PR19 Price Determinations

29 May 2020

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Section 1

Introduction

1.1 Thames Water is the largest water and sewerage company regulated by Ofwat, serving around 6 million customers in wastewater and around 3.8 million in water and operating around 32,000 km of water mains and 110,000 km of sewerage. We operate in the most densely populated area of England.

1.2 We accepted our Final Determination (FD) and so the outcome of the appeals process is unlikely to have a direct impact upon us. However, we have an interest in the outcome of the appeals as they are likely to have a material impact on the next price review (PR24).

1.3 Although we accepted the FD, the decision was finely balanced and we set out a number of our concerns in our acceptance letter, which we attach as appendix 1 and which is available on our website[1]. In particular, we would like to highlight the following paragraph from the response:

"We do continue to believe that Ofwat has missed an opportunity in PR19, to focus on longterm investment in our assets for the benefit of our current and future customers and the environment. Ofwat's FD strips back over £400m of totex from our Business Plan, at the same time as imposing a high penal rate for overspending against our allowances. Taking these factors alongside the Gearing Sharing Mechanism, and the historically low WACC, the FD encourages us to reduce rather than increase investment over the next five years."

1.4 However, our prime concern is over issues that are pertinent to the enquiry and may have an impact on PR24. In this submission we provide evidence and views covering:

- Totex modelling
  - Base cost modelling
  - Catch-up efficiency
  - Frontier shift modelling
  - Enhancement modelling
  - Uncertainty
- Upper quartile performance commitments and upper quartile costs
- Covid-19 impacts
- Gearing sharing mechanism

1.5 The information and arguments we include in this submission have been provided to Ofwat during PR19, with the exception of the econometric approach to enhancement

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1 https://corporate.thameswater.co.uk/-/media/Site-Content/Thames-Water/Corporate/AboutUs/Our-strategies-and-plans/letter-of-response-14-february-2020.pdf?la=en

expenditure example. During PR19 we provided an example of the approach applied to growth enhancement expenditure. As growth expenditure is included in the base models in the FD this example is no longer relevant, although we would be happy to share it with the CMA, if they would find it useful.

1.6 Further technical details concerning base cost and enhancement cost modelling are provided in appendix 2, Section C.

1.7 We hope the CMA find this information useful and we are happy to provide any further information that you would find helpful.

Section 2

Totex Modelling

A Introduction

2.1 Totex assessment is a very important aspect of any price control. There were a number of aspects of Ofwat's econometric modelling that we consider to be good and where we support them being maintained by the CMA. However, there were areas where we considered they could have been better. We set out below our suggestions on ways that we believe the CMA could improve these through the appeals process. We provide further detail in appendix 2.

2.2 Econometric models rightly play an important part in any assessment of efficient expenditure in the water industry and therefore it is crucial that they are of the highest standard. We recognise that they are tools, and that regulatory bodies still need to exercise regulatory judgement. This is particularly true when the future is clearly different to the past, for example, when there needs to be a step change in maintenance levels to provide improved resilience or when performance standards are being significantly increased above levels previously provided across the industry as a whole. Both of these aspects applied in PR19 and will continue to apply in PR24 as continued population growth and climate change result in increased needs for resilience.

2.3 We consider that there is an over-arching fundamental issue with the overall approach to the Totex assessment framework that the CMA should address. This is that companies are encouraged to provide as lean a totex plan as they can live with, in order to maximise their financial position under the cost sharing scheme[2] and increase their chances of being fast-tracked. In addition, the totex sharing rates then encourage companies to minimise their actual expenditure, which will then be reflected in the totex modelling assessment at the next review, creating a vicious circle. The inevitable result of these incentives, if continued without modification, is that companies will defer expenditure where they can, but this cannot go on for ever, if we wish to have resilient systems and to make the right long-term decisions for our assets and our customers.

2.4 To rectify this situation, it is essential that cost efficiency is assessed relative to the quality of outputs that companies are required to provide by customers and society, taking into account the drivers of quality e.g resilience levels, and the impact of company specific factors affecting the ability to deliver the required levels e.g. age of pipes. We provide further comments on this in section 3 below.

B Base cost modelling

2.5 The CMA's approach to totex modelling is likely to have a significant impact on Ofwat's approach to totex modelling at PR24. While the CMA is rightly focused on reviewing the

[2] Ofwat, Delivering Water 2020: Our final methodology for the 2019 price review, Figure 9.1

determinations of the four appealing companies, we consider that it is important that any the cost assessment approach adopted by the CMA is suitable to be used across the industry.

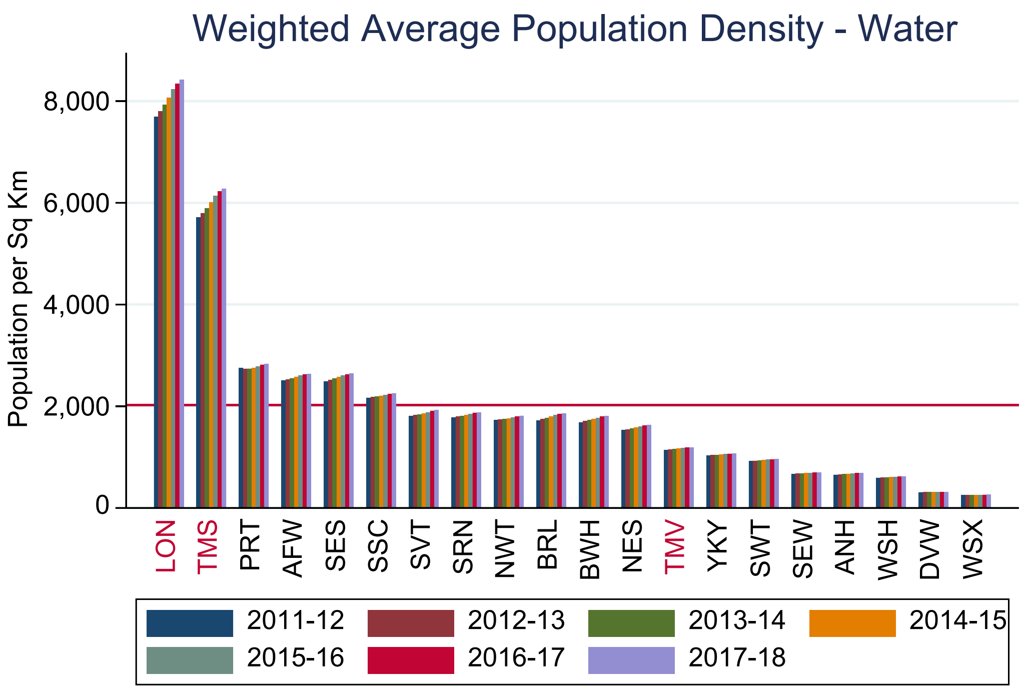
2.6 We set out below our considerations affecting base cost modelling covering:

- Modelling of density
- Efficiency catch-up
- Frontier shift
- Uncertainty

Modelling of Density

2.7 There is a wide range of density across the operating areas of the various companies in the water industry as shown in the chart below.

Chart 1: Weighted Average population density - Water



Source: Economic Regulation, Thames Water. ONS-Ofwat Data. LON=London, TMS=Thames Water, TMV=Thames Valley.

2.8 The treatment of density is very important in any econometric model of the water industry and while none of the four companies appealing are at the extremes of the density range, it is important that any model produced in the appeal to determine cost allowances properly account for the different impact of density on all companies, reflecting the variation across the industry.

2.9 We note that in the Bristol Water appeal of its 2015 price determination, the CMA rejected Ofwat's PR14 Translog approach in favour of a simpler and more restricted Cobb Douglas approach, which Ofwat initially favoured at the commencement of PR19 modelling process.[3] The evidence that Ofwat reviewed during PR19 convinced them of the need to change the functional form for the water distribution, water resources and wholesale water to properly account for density and improve the overall reliability of the econometric models.

2.10 We provide in appendix 2, Section B analysis to show that the use of the semi-translog functional form (e.g., including the quadratic term of density) used by Ofwat, improves the performance of the econometric modelling in the wholesale water business and is appropriate for assessing base cost modelling across the industry. We also highlight that the points raised by Anglian Water regarding the Variance Inflation factor (VIF) and multicollinearity in Ofwat's models, are based on a misinterpretation. When the appropriate adjustments are made, as set out in appendix 2, Section B, the multicollinearity issue disappears.

2.11 We therefore support the continued use of Ofwat's semi-translog functional form in assessing base costs for the water industry.

Catch-up Efficiency challenge

2.12 Where Ofwat use Random Effects (RE) models there is a lack of clarity, as we set out in our response to the Draft Determination[4] (DD), over the unobserved individual heterogeneity company specific variable. Ofwat assume this is due to inefficiency but there is no evidence to support this position. It could equally be the result of geographical characteristics or other unobserved characteristic of the companies.

2.13 Further clarification and understanding of this factor could improve the treatment of efficiency assessment in the econometric modelling of base costs and its consequences on the catch-up efficiency challenges. Further details are included in appendix 2, Section B.

Frontier Shift

2.14 In PR19 Ofwat applied a frontier efficiency shift based on the Total Factor Productivity (TFP) analysis of various industries undertaken by Europe Economics. It is a big step to assume that the productivity improvements in these sectors can be applied directly to the water industry and that the same incentives for technology improvements apply across these sectors and the water industry. The water industry is subject to strong cost efficiency incentives and so it appears odd not to include the impact over time of cost changes in the water industry.

2.15 In our view, any assessment of frontier shift should include either a proper treatment of time trend in the base cost models or use a direct estimation of productivity using econometrics in the water and wastewater industries.

[3] See Ofwat Cost Assessment for PR19 – a consultation on econometric cost modelling. March 29, 2018.
[4] Thames Water response to Ofwat's PR19 draft determination, TW-DD-001, August 2019

C Enhancement expenditure modelling

2.16 A significant area of difference between Ofwat and companies at PR19 was over the appropriate level of enhancement expenditure. Industry requested £11.13bn while Ofwat provided allowances of £8.27bn, which is equivalent of a 25% efficiency challenge, whereas on base costs the efficiency challenge at the industry level is only 0.4%.[5] Ofwat relied on relatively simple models, for example the only cost driver for metering expenditure was the number of meters installed, which needed to be supported with deep dive assessments. In our view this is an area where improved econometric modelling could be used to improve objectivity and reduce the subjectivity of the deep dive approach across significant amounts of expenditure.

2.17 During PR19 we undertook dynamic panel modelling of growth expenditure, when this was being assessed outside of the botex models and found that the enhancement modelling was improved by this approach.

2.18 We have more recently considered this approach for the assessment of metering expenditure and found similar conclusions. The predictive power of the econometric models were significantly improved by the use of dynamic panel models.

2.19 The CMA may find this approach useful in assessing these types of expenditures in the appeals. Appendix 2, Section C, includes the analysis we have undertaken to improve the modelling of metering allowances, which the CMA may wish to consider in its deliberations. We would be happy to provide the CMA with any additional information or analysis if this would be useful.

2.20 This approach has the potential to improve the assessment of these expenditures in order to reach more reliable and objective results that will be beneficial for customers, the environment and companies.

D Uncertainty

2.21 We believe that the cost assessment process should consider the role that uncertainty plays in the forward projections (e.g., with or without the econometric models). The assessment should control for risks/uncertainties to update the current approach into a more realistic scenario given the current environmental characteristics that we live with today (e.g., health crises, severe climate shocks, etc.).

2.22 From the econometric point of view there are different approaches on how to start incorporating this issue. For example, treating the output (e.g, water distributed) as an endogenous driver in order to capture the uncertainties that are surrounding the cost function through the use of the expected output and not the realised output. This could provide better assessments and also prepare and put companies in a better position to deal with unknown scenarios in the future (see appendix 2, Section D for more details).

[5] See Ofwat PR19 final determinations: Securing cost efficiency technical appendix (updated April 2020) p. 167-68.

Section 3

Upper quartile performance and upper quartile costs

3.1 A significant area of dispute between companies and Ofwat at PR19 was over the setting of performance commitments (in particular the use of simple upper quartile benchmarking on a forward projection basis for many important performance commitments) combined with an upper quartile cost efficiency assessment.

3.2 In the FD, Ofwat assess upper quartile performance for each key performance commitment individually and assess upper quartile performance for each price control individually. Ofwat then expect companies to achieve these upper quartile performance levels across all performance commitments and upper quartile costs in all price controls at the same time.

3.3 As demonstrated in our Draft Determination (DD) response in August 2019, no company has been performing at upper quartile for both cost and service, across water, wastewater and retail during AMP6. This means that the benchmark that Ofwat has set is unrealistic and not a reasonable basis of setting allowances.

3.4 Ofwat's approach does not appear to recognise that improving quality and service incurs a cost and increasing performance to upper quartile levels will require additional totex beyond the levels allowed in previous AMPs and the levels allowed in AMP7.

3.5 As highlighted in Section 2A above, there is a need to integrate the assessment of service quality and costs if the appropriate levels of service and resilience are to be provided for customers and society.

3.6 The totex modelling takes account of many company specific factors in its assessment of the efficient level of expenditure, for example density. It is inconceivable that many of these factors do not also influence the ability of companies to achieve specific levels of performance, yet this is not reflected in Ofwat's approach to performance commitment benchmarking.

3.7 If all companies were delivering the same level of service historically then the cost assessment may largely deal with the appropriate costs. However, while historical performance levels show significant variations and performance and resilience levels are being improved the cost modelling cannot alone deal with the issue and so adjustments should be made to the performance commitments.

3.8 Ideally there should be an integrated approach to performance commitments and totex modelling. We accept that it not easy to integrate totex assessment and quality factors and we acknowledge that there could be mixed/perverse incentives were factors such as the level of leakage included in the totex assessment.

3.9 However, there will be drivers of leakage, for example, age of pipes, density, soil types etc. If variables can be identified to robustly model efficient levels of performance, then the incorporation of these variables into the cost assessment modelling could act to integrate service performance and cost assessment and appropriate efficient costs could be provided for the levels of resilience and service expected from companies.

3.10 We consider that the CMA should consider the impact of heterogeneous factors when assessing appropriate levels for performance commitments and take into consideration the impact of service and quality levels, on the totex assessment, which will likely vary by company depending on their specific circumstances.

Section 4

Covid-19

4.1 The Covid-19 pandemic was clearly entirely unexpected both at the time that Ofwat published their final determinations for PR19 and after the deadline to request an appeal for companies had passed.

4.2 We understand that the CMA will need to undertake the appeals as it finds the world today. We also note that Ofwat have acknowledged that there will be impacts from Covid-19 on company performance and delivery, and that they will consider these as part of their annual PR19 reconciliation process. Companies now have many in-period adjustments and a number of performance measures (both financial and reputational) that require delivery in line with an assumed profile over the five year AMP7 period. This process will therefore need to commence no later than the end of 2020-21. It will need to take account of the unprecedented and urgent nature of the decisions that companies have needed to make as we manage this crisis, and as we prioritise our focus on continuing to provide essential services to our customers and keeping our staff safe.

4.3 The series of lockdown measures introduced by the UK Government since mid-March to combat the spread of Covid-19, including social distancing, the closure of public buildings such as schools and shops, and imposing limits on construction activities alongside promoting a 'stay home' message has had an immediate impact on some of the activities and services we undertake. This is already affecting and will continue to impact a number of our performance commitments and our overall delivery.

4.4 We have assessed the impact on our performance commitments across four main categories:

- Customer contact required: Where face to face contact with a customer or physical access to a customer's premises is required. For example, where there is a need to enter a customer's property or where stakeholder engagement is a key part of delivery;
- Customer behaviour change: Where there is a change in customer behaviour. For example, people remaining at home for sustained periods and changing their patterns of water usage;
- Staff shortage: The impact on our workforce from prioritising key activities. For example, our ability to carry out planned work in the field due to staff shortages, including the availability of contractors;
- Work mode constraints: Where there are changes in working patterns which provide constraints, given the number of people working from home, both customers and Thames Water staff. For example, the ability of teams to attend sites together.

4.5 Using this approach, we consider that a number of common performance commitments are likely to be seriously affected and we encourage the CMA to consider, for example:

- Per capita consumption: where the level of consumption has been adversely affected by the increased level of homeworking and hand washing and the reduced ability of companies to undertake consumption reduction activities such as home visits and installation of metering. We have seen a 10-20% increase in level of metered consumption on our smart meters which is still increasing – and we will continue to monitor the impact over the coming months. There would appear to be a *prima facia* case for this performance commitment to be made reputational until we can determine the impact in both the short and longer term.
- C-Mex: the methodology has been carefully considered and calibrated over the trial period including face to face customer engagement. As this is no longer possible there is a strong case to suspend the measure for at least the first year.
- D-Mex: the approach relies on engagement with developers. However, with the significant reduction in workload for the developer sector over the first quarter, it is likely that any feedback could will be based on such low numbers that are too low to be reliable.

4.6 It is also likely that a number of other common performance commitments will have been and may continue to be affected. This includes internal sewer flooding and pollutions as a result of increased blockages, where we have seen a material increase due to changes in customer behaviour. We are also monitoring the impact on leakage, mains repairs and supply interruptions among others.

4.7 We note that Ofwat, Water UK and colleagues across the water sector are aiming to work together to consider and assess the impact of Covid-19 on both companies and on the regulatory framework. We are fully supportive of this process. We note above, some of the key impacts that we are seeing at present, to support the CMA in your ongoing review which is inevitably taking place in parallel to this work.

Section 5

Gearing Sharing Mechanism

5.1 While we have accepted the FD in the round, we continue to disagree with the underpinning principles behind Ofwat's Gearing Outperformance Sharing Mechanism, as set out in our DD response.

5.2 At the very least it is an act of retrospective regulation, as it penalises companies for past decisions without allowing an appropriate time period in which to adjust. Making material adjustments to capital structure is not an overnight activity and we suggest this mechanism should not have effect before 2025 to allow companies time to be able to react to the incentives.

5.3 We also continue to disagree with the underlying rationale:

- We disagree with the implication that gearing above 65% implies a lack of financial resilience; no evidence is presented that the quantum of equity invested in TWUL, or other companies with gearing in excess of the current notional assumption, is inadequate to cope with the cost shocks that it might face;
- Ofwat's GSM ignores a fundamental tenet of corporate finance theory: namely, that the cost of equity naturally increases as the ratio of debt to equity rises. Ofwat's GSM is asymmetric in that it seeks to reflect in prices, the interest rate benefits of securitisation arrangements but not the associated costs and risks to equity;
- Notwithstanding statements to the contrary, Ofwat's GSM effectively abandons a long-standing regulatory principle that financial arrangements are a matter for companies, as the proposals severely penalise companies with capital structures that deviate materially from the notional gearing assumption;
- Ofwat's GSM penalises highly levered companies with more efficient debt management (a lower actual cost of debt creates a bigger spread with the cost of equity, which turns into higher penalty).

Section 6

Appendix 1 - TW Final Determination acceptance letter

Rachel Fletcher
Ofwat (by email)

Name Ian Marchant
E-Mail Ian.marchant@thameswater.co.uk

14 February 2019

Dear Rachel,

TWUL's decision not to request a referral

The Kemble and TWUL Boards have assessed Ofwat's Final Determination (FD) in detail. While the decision has been difficult for the Board, and was finely balanced, I can confirm that we have decided not to require Ofwat to refer the matter to the Competition and Markets Authority (CMA). We wish to move forward positively to focus on continuing to improve service to our customers, working collaboratively with Ofwat.

The FD includes some positive improvement for TWUL compared to the Draft Determination (DD) and I would like to thank you and the team for this. These improvements move the settlement closer to our position as set out in our response to the DD. The positives for us include the increase in totex allowances relative to the DD, the gated process enabling us to progress up to £180m in funding for North East London resilience, the movement of some key performance metrics relative to the DD and the attenuation of some ODI penalty rates.

TWUL's concerns with the FD remain

There are some elements of our FD where we feel that we must be transparent with you about the scale of challenge that the package sets for us, and so manage expectations regarding our performance over the next five years.

As we made clear in our August 2019 DD response, we do not necessarily expect to be able to operate within the cost and service thresholds set out in the FD. Our central expectation is that we will incur net overspends and net penalties. We note that the language and detail contained in Ofwat's suite of FD documents set a clear expectation that some companies will need to overspend against allowances and that some companies will incur significant penalties against Performance Commitments in the next regulatory period. The design of the C-Mex measure is a good example of this. Companies that score below the median on C-Mex will incur financial penalties even if customers of that company have seen a marked improvement in service.

For the avoidance of doubt, while this means we expect to be able to carry out our regulatory activities and to meet our statutory obligations, based on what we know today we cannot be certain that we will be able to deliver all of the outcomes set out in the FD, which we interpret as referring to the Performance Commitments. We expect that any reasonable test of whether we are meeting our obligations will take account of the funding that Ofwat has allowed.

Ofwat's settlement is most challenging on the water network, and we are disappointed that the case we made for additional investment in resilience was not accepted by you in the FD. As we seek to accommodate the necessary investments in the envelope of totex allowed, we will have to make some very tough choices. This inevitably means that we will not be able to proceed with the full range of projects we had planned to de-risk the network, increase resilience and establish a more secure supply for our customers.

We do continue to believe that Ofwat has missed an opportunity in PR19, to focus on long-term investment in our assets for the benefit of our current and future customers and the environment. Ofwat's FD strips back over £400m of totex from our Business Plan, at the same time as imposing a high penal rate for overspending against our allowances. Taking these factors alongside the Gearing Sharing Mechanism, and the historically low WACC, the FD encourages us to reduce rather than increase investment over the next five years.

Future engagement

One of our early tasks in the next price control period will be to work with Ofwat on the conditional allowances contained in the FD and seek to progress these through a gated process that delivers this necessary investment in an efficient way for the benefit of our customers. For North East London, work is progressing well, and we are finalising plans to share with you in the coming weeks.

We are very disappointed that on the additional investment for mains replacement in Central London, Ofwat have chosen to include a clause requiring, "substantial shareholder contribution" to this allowance, without providing any justification for this approach, any details on what you are asking for or how this would work in practice. We are concerned that, while Ofwat recognise the need for the investment in the interests of our customers, this clause could prevent us from making this investment in the next five years. Given the unusual nature of the clause, we feel that we will need some time to discuss with Ofwat, understand the basis of the clause, and work constructively with Ofwat to jointly find a solution that ensures this essential investment in London's water network goes ahead. Our initial view is that we are therefore likely to need more time to address these issues with you.

We are continuing to undertake significant work to finalise our delivery plans for the next regulatory period, based on the FD, and would welcome the opportunity to work constructively with Ofwat in sharing these plans and keeping you informed of our delivery over the next five years.

While this will be an incredibly tough period for TWUL, as we balance the implications of the FD with our delivery plans, we are committed to doing all that we can to increase our efficiency and continue our work to deliver an improved service for all of our customers.

I must stress that this was a finely balanced decision. Our conclusion is that we would be better to spend the next 12 months working with Ofwat, our customers and our stakeholders to refine our delivery plans for the next five years and to build a solid case for further investment in the network in the PR24 price control, than to spend that time at the CMA. We look forward to working constructively with you over the critical coming months.

Yours sincerely,

Ian Marchant
Interim Executive Chairman

Section 7

Appendix 2 - Insights from the PR19 Cost Assessment Process

A Summary

7.1 This appendix presents our main comments and suggestions related to the PR19 Cost Assessment Process. It has been produced by Thames Water for the purpose of helping the CMA to have a broader view of the modelling approaches and areas of potential improvements in its enquiry.

The key findings of this report may be summarised as follows:

- There is empirical evidence derived from Ofwat's initial 2018 models that the effect of density needed to be expanded (i.e., square term). This expansion sits between the full translog and the Cobb-Douglas functional forms (i.e. semi-translog).
- Under the semi-translog functional form the predicted vs. actual cost difference outcomes show a significant improvement when compared to the Cobb-Douglas. The better performance of the semi-translog vs. the Cobb-Douglas is also explained as evidenced in the square terms, in the Final Determination (FD) models for wholesale water, which are statistically significant with no evidence of omission and misspecification (see section B).
- Distinguishing between very small and very large companies is also crucial for the models. Hence, the semi-translog functional form that accounts for variation of density economies with output is sensible. By including this form, we allow the model to capture different levels of density across the industry.
- We welcome the significant and positive improvement from Ofwat's initial restricted approach in 2018 into the FD models, by including the square term of density in the wholesale water models. This provides a more objective base cost function supported by empirical and theoretical evidence.
- Enhancement modelling has the potential to be improved by using Dynamic Panel models that capture the lumpiness or irregularities of this type of investment/expenditures. The example on enhancement metering provides promising results (see section C).
- Enhancement expenditures (when appropriate) should be modelled or at least explored using dynamic panel data as an alternative of what has been proposed in the PR14 and PR19 reviews. This approach has the potential to improve the assessment of these expenditures in order to reach more reliable and objective results that will be beneficial for customers, the environment and companies.
- Efficiency challenges can be improved by a different combination of methodologies.

- Uncertainty is becoming an important element in the economy and the production process of different industries. There are different approaches that could help to start controlling for this impact in the cost assessment econometric models.

7.2 The aim of this document is to present the positive outcomes we derived in the PR19 learning process with Ofwat related to the base cost modelling.

7.3 Section B focuses on base cost modelling and the treatment of density and the potential on how the efficiency/productivity challenge could be improved.

7.4 In Section C, we propose an alternative on how enhancement cost models/assessment could be improved given the significant material impact that this area has on business plans and its importance for customers.

7.5 Finally, Section D highlights the importance on how uncertainty should be included and considered in future price reviews as an important element of cost assessment.

B Base Cost Econometric Modelling

Density

7.6 Base cost models (botex) for wholesale water and waste were developed between Ofwat and the Industry during PR19 at the Cost Assessment Working Groups and the 2018 Econometric Consultation[6]. The econometric models presented by Ofwat at the consultation, in particular the wholesale water models, were too restricted (e.g., Cobb-Douglas) yielding unreliable or not objective econometric/statistical results. The main concern that those water models had at the time was the treatment of density, either measured as a weighted population density or the average density measured as the proportion of connected properties over the length of mains of the water network.

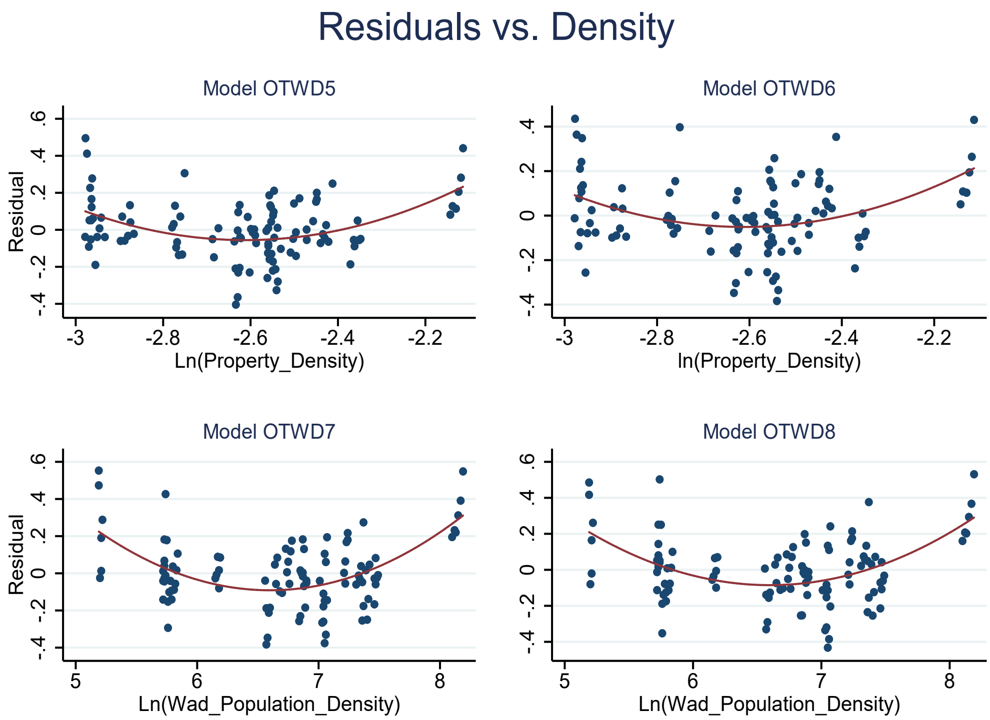
7.7 For those water models in the 2018 econometric consultation that included density (property and population density; Ofwat models OTWD5-8) we analysed the residuals as shown in Figure 1 below. The reason of doing this was to identify any potential misspecification that these models presented at the time (see p-values for the Ramsey RESET Test[7] for models OTWD5 to OTWD8 where it ranges between 0.002 and 0.064). A basic form to check for specification is by using a simple chart that plots the density variable vs. the residual of the model. For consistent estimation when using OLS as an estimator[8] the residuals need to have an expected value conditional on the explanatory variables (i.e. density) equal to zero. Figure 1 suggests that the residuals were dependent on the level of density either property or weighted population density,

[6] See Ofwat Cost Assessment for PR19 – a consultation on econometric cost modelling.
[7] The Ramsey Reset test is an empirical tool that helps to determine if higher orders terms (e.g., square, interactions, etc.) are missing in the model by using the fitted values of the model. This test is not a test for omitted variables, as there is not such a test. It only suggests for square, interactions terms missing in the model based on the variables explored.
[8] Ofwat models at the time were pooled models estimated by pooled OLS, the Random Effects models estimated by GLS were not considered at the time of the 2018 econometric consultation.

which is not in line with the OLS assumptions to produce consistent estimations. The charts in Figure 1 reveal a U-shape pattern for any type of density used. The graphs show that at low and high levels of density the residuals are higher than the estimated value and for middle values of density the real value of costs are lower than the estimated value[9].

7.8 This exploration of the residuals in addition to the RESET test presented for each model (OTWD5-8), suggests that the shape of the cost function is not correctly specified when using a Cobb-Douglas cost function in, for example, treated water distribution.[10]. A way to resolve this issue is by making the restricted Cobb-Douglas functional form into a more flexible form.

Figure 1 – Residuals vs Density



Source: Economic Regulation, Thames Water

7.9 A more flexible function compared to a restricted one such as the Cobb-Douglas can be implemented by using a full translog cost function or a semi-translog, where the latter sits in the range between the Cobb-Douglas (full restriction) and the full translog (full flexibility). Any functional form in this range will contain some production restrictions that need to be explored and tested. We recognise CMA comments on the use of a full

[9] See for example Davis and Garces (2010, pp. 137-39) **Reference**: Davis, P. and Garces, E. (2010). Quantitative Techniques for Competition and Antitrust Analysis. Princeton University Press., or Nerlove (1963) for similar analysis and suggestions. **Reference**: Nerlove, M. (1963). Returns to scale in electricity supply. In Measurement in Economics (ed. C. Christ). Sandford University Press.

[10] This analysis can also be extended for the wholesale water models with similar results and conclusions, for instance.

translog at PR14 for wholesale water. CMA comments are summarised by CEPA as follows (see CEPA report PR19 Econometric Benchmarking Models, pp. 9):

a) Translog models contains higher-order terms, square terms and cross-terms which are difficult to interpret and ambitious given the size of the sample.
b) The Translog specification used by Ofwat at PR14 did not totally follow the standard translog cost function from economic theory as interaction and square terms were only applied to a subset of the identified cost drivers.

7.10 With respect to (a), each interaction provides information related to the data and structure of the industry. This needs to be understood by the results provided by the model. Regarding (b), it is true that the refined models from Ofwat at PR14 were not a full translog model. However, this does not imply that the specification of the model was incorrect. In fact, when lower levels of the full translog functional form are specified, it is because we are referring to different types of production structures[11]. These different types of production structures are known in the literature as homothetic or homogeneous production structures[12.] Moreover, these lower levels of specification of the full translog functional form (i.e., homothetic/homogenous) can also incorporate other restrictions by using for example a unitary elasticity of substitution of inputs which eliminates some terms in the translog functional form. All these restrictions need to be tested in order to really understand the structure of the industry that is behind the data by following an appropriate analysis of the cost and production structures[13]. Finally, as Chambers (1988, pp. 159) mentions regarding the treatment of functional forms: "*within the context of the problem, the form should be as general as possible and should restrict the ultimate outcome as little as possible*"[14.]

7.11 This type of analysis on functional forms that explores different types of production structures is missed and not recognised by CEPA and CMA reports in the past. In addition, the CMA Bristol PR14 report applied only to the wholesale water value chain

[11] For a detail analysis on how to obtain special functional forms from the full translog see Nadiri, M.I (1982, pp. 466). **Reference**: Nadiri, M. I. (1982). Producers Theory. Chapter 10 in Handbook of Mathematical Economics edited by Kenneth Arrow and Michael D. Intriligator, Volume 2. Reprinted edition 2007. For example, Armstrong and Sappington (2007, pp. 1642), summarise the economic principles and incentives that are derived in the minimisation cost assumption that is reflected under yardstick competition. **Reference**: Armstrong, M. and Sappington D. (2007). Recent Development in the Theory of Regulation. In Handbook of Industrial Organization, Vol. 3 edited by Mark Armstrong and Robert H. Porter. pp. 1557-1687. For an extensive and more detail analysis on how duality theory holds when regulation restrictions are explicitly incorporated in the cost minimisation problem **see** Ouellette, P. and Vigeant, S. (2001). Cost and Production Duality: The Case of the Regulated Firm. Journal of Productivity Analysis, 16, 203-224.

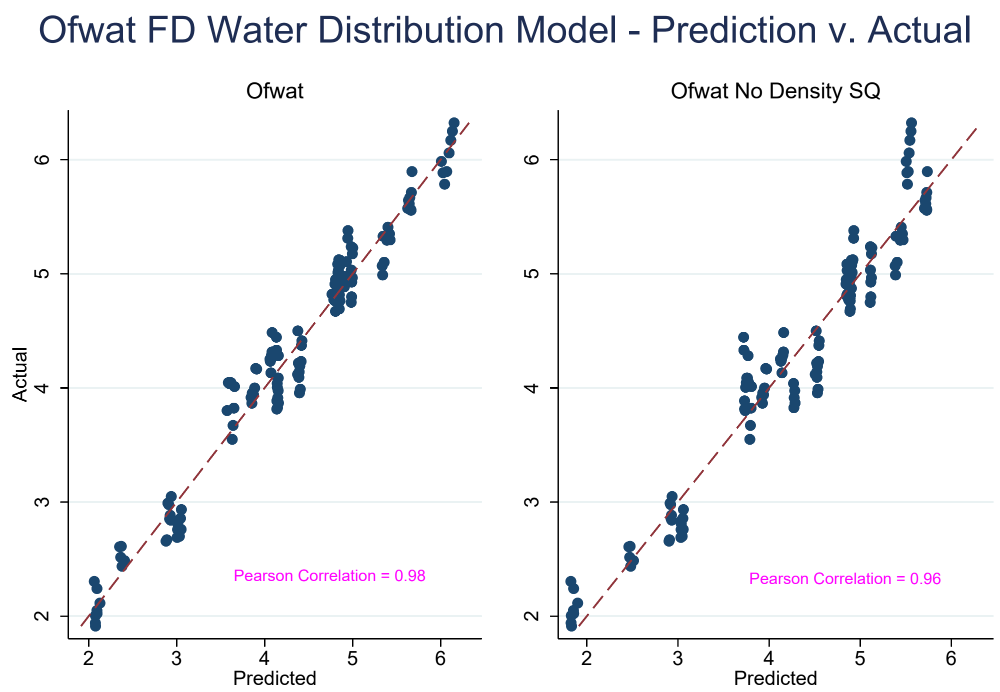
[12] See Varian (1992, pp. 17) for an example on homothetic production functions structures. **Reference**: Varian, H. (1992). Microeconomic Analysis. Third Edition, W.W. Norton & Company Ltd.

[13] For a detailed example on how to follow an appropriate analysis of cost functions see Christensen and Greene (1976), **Reference**: Christensen, L. and Greene, W. (1976). Economies of Scale in U.S. Electric Power Generation. The Journal of Political Economy. Vol 84. No. 4, Part 1, pp. 655-676, or Farsi and Filippini (2009) to mention some examples, **Reference**: Farsi, M. and Filippini, M. (2009). An analysis of cost efficiency in Swiss multi-utilities. Energy Economics, Vol. 31, pp. 306-315.

[14] Chambers, R. (1988). Applied Production Analysis, A dual Approach. Cambridge University Press.

model and did not apply at the disaggregated level (e.g., resources, treatment, and distribution). This comment from the CMA might generate misleading conclusions as different parts of the value chain are operated by different types of production structures that need to be taken into account, especially when modelling disaggregated models. It is not objective to assume a particular functional form without first exploring the production structures that are behind the data and that are fundamental to estimate the appropriate functional form and the effect of the coefficients, otherwise there is a risk of misspecification/misrepresentation of the costs.

Figure 2 – Ofwat FD Water Distribution Model – Prediction v. Actual



Source: Economic Regulation, Thames Water.

7.12 Including the right production structure (restrictions) increases the probability of finding robust models that take into account the appropriate specification[15]. Moreover, this will mitigate the risk of excluding fundamental drivers (i.e., regional wages) thereby avoiding problems such as omitted variable bias (an endogeneity issue between the

[15] Armstrong and Sappington (2007) mention how important is to take into account the differences in operating environments, in particular they mentioned that when companies are not identical as Shleifer (1985) mentions, "*Failure to adjust adequately for innate differences in operating environments could lead to financial hardship for some firms, significant rents for others, and suboptimal level of cost-reducing expenditures*." (see Armstrong and Sappington (2007, pp. 1642)). **Reference**: Shleifer, A. (1985). A theory of Yardstick Competition. The RAND Journal of Economics. Vol 16, No. 3, pp. 319-327.

error term and the drivers of the model)[16]. Therefore, we welcome the significant and positive improvement from Ofwat Final Determination (FD) models in all the wholesale water models (e.g., water resources, treated water distribution and wholesale water) by including the square term of density in all the specifications to bring a more objective base cost assessment supported by empirical and theoretical evidence. As an example, Figure 2 depicts the implication of excluding the square term of density on the prediction and fitness of the FD model for treated water distribution[17]. Excluding the square term reduces the correlation between predicted and actuals (e.g., 45-degree line y=x; see Pearson correlation), and also it shows a significant spread on the results when the density square is excluded. Its inclusion provides a better fit across the whole industry.

7.13 Finally, we want to add an extra comment regarding Anglian Water's appeal case with respect to the use of the Variance Inflation Factor (VIF) and multicollinearity. Anglian Water identify that the VIF values are high by the inclusion of the square term of density. Any translog/semi-translog model should normalised at the mean for all explanatory variables so that the translog expansion is around the sample mean across all companies and the first order coefficients can be interpreted as elasticities at the sample mean. Through this process and by calculating the VIF implied behind this, the multicollinearity issue that is highlighted by Anglian Water disappears and shows that the current Ofwat's models do not present multicollinearity. Therefore, we support Ofwat approach and interpretation of the VIF[18].

Frontier Adjustment / Efficiency Challenge

7.14 Ofwat catch-up and forward-looking efficiency challenges could be improved to have a more consistent and objective approach.

7.15 <u>Catch-up efficiency challenge</u>: The Random Effects (RE) model assumes a random variable that captures unobserved individual heterogeneity (α_i). This model assumes that the unobserved random individual effect is distributed independently of the regressors (e.g., cost drivers). The error of the model then can be written as a composed error term (e.g. $u_{it} = \alpha_i + e_{it}$) assuming that this error term is not correlated with any of the regressors (e.g., the fixed effects model relaxes this assumption). Ofwat is not clear on what the α_i actually captures in their models. None of the IAP, DD or FD supplementary technical appendixes define or clarify the role of the unobserved heterogeneity. For example,

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[16] The effect of omitted variable bias in the model generates an inconsistency problem with the estimated coefficients. "*In general the inconsistency could be positive or negative and could even lead to a sign reversal of the OLS coefficient*" (see Cameron and Trivedi (2005), pp. 93.), regarding the consequences of omitted variable bias. **Reference**: Cameron, A. and Trivedi (2005). Microeconometrics, Methods and Applications. Cambridge University Press.

[17] Moreover, the overall R^2 without the squared term of density is reduced to 0.94 from 0.97 when the square term is included.

[18] Reference of the PR19 final determinations: Cost efficiency – response to common issues in companies' statements of case on paragraph 3.30, p.21 (2020). In addition, we also agree with United Utilities response on the Third Parties response, section 3.4, p. 11.

- Is α_i capturing inefficiency?
- Is α_i an unobserved heterogeneity such as geographical characteristics?

7.16 This determines whether the composite error is company specific and therefore needs to be adjusted to be consistent across the industry efficiency rankings.

7.17 Depending on what is assumed to be captured by α_i then it is possible to have a better understanding on the efficiency catch-up calculations and its impact on base cost calculations.

7.18 Forward-looking efficiency challenge: Including an appropriate treatment of time trend in the cost function models or estimating a production function to forecast or extrapolate productivity levels for AMP7 would be a good complement to the current approach that Ofwat has imposed for AMP7. The current approach used on PR19 could be too subjective by "selecting" different sectors linked to the water and wastewater industries which has brought a lot of discrepancies across the industry (e.g., see Europe Economics (EE) and the sectors chosen for the analysis and all the different responses from consultants). In addition, the EE approach is based on TFP which relies on different assumptions such as perfect competition and the absence of measurement error[19]. These assumptions would need to be explored on the industries that have been chosen to test their robustness, otherwise we could end up in over/underestimated indexes of TFP.

7.19 As stated by Berry et all. (2019)[20] "*industries are so heterogeneous that careful industry-specific studies are also required, and sorely needed.*" This emphasises the different structures and technological patterns that each industry has. Applying the current Ofwat approach of taking similar industries and its different levels of productivity challenges (TFP) to produce a single TFP that applies to water and waste is forcing the industry to have the same efficiency improvements that similar peers have, which could be damaging and misleading. It also omits the large heterogeneity that is presented in each industry (e.g., water, waste, manufacturing, construction, etc.) as mentioned by Berry et all. (2019) and Syverson (2012)[21].

7.20 An objective approach would be, for example, using parametric approaches on the estimation of production functions in order to understand the productivity of the sector itself[22]. Using a parametric approach or any other methodology that helps us to understand the productivity trends of the industry could bring an important picture of the technological improvement patterns of the industry. This analysis of the industry could help to control more accurately the heterogeneities that belong exclusively to the water and wastewater industries and its results could also be balanced out (e.g., combining/weighting) with the current Ofwat approach that is based only on external industries that have different technological and economic incentives.

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[19] See Biesebroeck van, J. (2007) Robustness of Productivity Estimates. Journal of Industrial Economics, Vol. LV.
[20] See Berry, S., Gaynor, M. and Morton, F. (2019). Do Increasing Markups matter? Lessons from Empirical Industrial Organization. Journal of Economic Perspectives, Vol 3. Number 3. Pg. 44-68.
[21] See Severson, C. (2012). What Determines Productivity? Journal of Economic Literature. 49:2, 326-365.
[22] See for example, Abbot, M. and Cohen, B. (2009). Productivity and Efficiency in the water sector. Utilities Policy, 17, 233-244, for a summary of different approaches in the water sector for productivity estimations.

C Enhancement Approach

7.21 Enhancement or investment models are a fundamental part of the cost allowances for PR19. In the 2018 Econometric consultation Ofwat proposed Static Panel Data models for water and waste enhancements activities. For the DD and FD, Ofwat used a simpler set of econometric or unit cost models (e.g., for instance, in enhancement metering, a cross-section econometric model is used).

7.22 Ofwat recognises the key issue on enhancement modelling: *"the efficient level of enhancement costs is more difficult to estimate than for base costs. Due to their irregular nature, there is less opportunity to compare the cost of required enhancement solutions between companies, and in some areas the exact requirements may be subject to uncertainty"*[23]. The challenging part of enhancement modelling is therefore the irregular nature of investments/enhancements or the lumpy patterns observed across the industry on different types of enhancements activities in water and waste, within and between companies.

7.23 The aim of this section is to provide an alternative approach to the Cross-Section, Static Panel Data, or unit cost approaches proposed by Ofwat during the PR19 cost assessment enhancement process. This section focuses on Metering as it represents an important proportion of enhancement expenditure and one of the largest reflecting within company variation across the different enhancement activities in the water industry[24.]

7.24 The alternative approach we propose to be explored for a more objective assessment relies on Dynamic Panel Data models. The nature of enhancement investments expressed as lumpy or irregular levels across the industry can be modelled using these types of models. The dynamic approach allows us to capture in a consistent way the different dynamic patterns (irregularities) of investments that each company faces at any particular period of time (e.g., yearly) by introducing the lagged dependent variable (e.g., the amount invested in metering in previous years, t-1, t-2, t-3, for example) that captures the history and cyclical patterns of investments within a company. It also allows us to understand the persistence of enhancement decisions of the past in the present, or to capture the magnitude of adjustment investments/enhancement expenditures.

7.25 Companies' investments/expenditures show different cycles and patterns over AMPs. For example, when a new development project or metering strategy is designed for three/four or five years there may be during this time some reallocation of resources that could over/underestimate the initial expenditure/investment plan, yielding a lumpy/adjustment investment series (see Peck (1974))[25]. Furthermore, in a regulatory

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[23] Ofwat, 'PR19 draft determinations: Securing cost efficiency technical appendix', July 2019, pp. 35-37, Section 4.1.
[24] During PR19 we undertook dynamic panel modelling of growth expenditure, when this was being assessed outside of the botex models and found that the enhancement modelling was improved by this approach. We have the econometric results and always happy to share them if required.
[25] Peck (1974) is one of the earliest articles that highlights the lumpy nature of investments in utilities. The model introduces dynamic components in the empirical specification such as the *fixed lag model* used to explain the lumpy investments made by the firm. His investigation is applied to a sample of 15 firms in the U.S. electric utilities industry

framework, investments can also be driven by different regulatory incentives (see Cambini et al. (2016)[26] (2011)) or macroeconomic shocks (e.g., changes in demand). An investment in period t could be influenced by the dynamic effect of previous events at t-1, t-2, etc. which basically reflects previous managerial expenditure decisions, cyclical investment patterns, etc. Therefore, a more realistic and appropriate empirical specification of investments/enhancement expenditures should control for these dynamic patterns (e.g., lumpiness, irregularities)[27]. The following sections investigate the case of enhancement metering by understanding the patterns of expenditure and also through the use of different econometric approaches such as static and dynamic panel data modelling procedures.

Descriptive Statistics on Metering

7.26 Figure 3 shows the investment/expenditures levels on metering for each company between 2011-12 to 2017-18 for actuals and forecasts through to 2024-25. It shows the lumpy or irregularity of metering investment within and between companies across the industry. For example, ANH investment levels are quite volatile with a min and max of £2.3m and £15m, respectively. Similarly, TMS has a min of £15m and a max of £68m, whereas the industry has an average investment across the period of £7m per year. Many small companies have very low levels of metering investment; nearly zero (e.g., PRT has a min and max of £0.19m and £1.5m, respectively) which reflect the different strategies, conditions and heterogeneities that each company faces. For

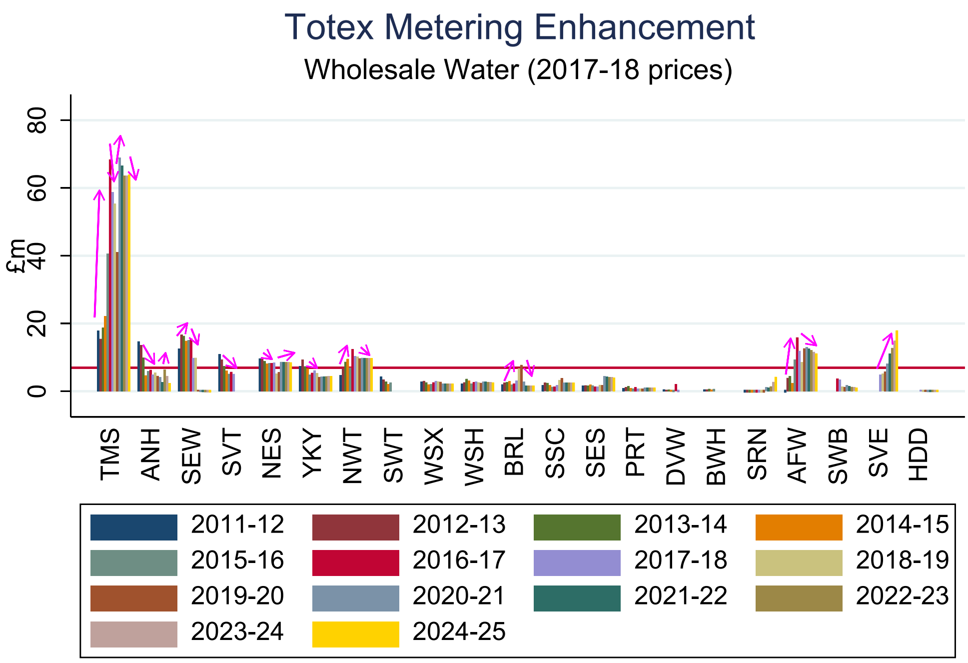
between 1948-1969 using Bayesian econometrics. **Reference:** Peck, S. (1974). Alternative Investment Models for Firms in the Electric Utilities Industry. *The Bell Journal of Economics and Management Science*, Vol. 5, No. 2, pp. 420-458.

[26] Cambini and Rondi (2011) use a dynamic panel model of investment in 15 EU Public Telecommunications Operators to account for investment adjustments. Similarly**,** Cambini et al. (2016) uses a dynamic accelerator model of investment to test the impact of output-based incentives on the investment rate survives after controlling for other determinants using a dynamic panel data model and information on the largest electricity distribution operator in Italy with 115 distribution zones between 2004-2009. **References**: Cambini, C. and Rondi, L. (2011). Capital structure and investment in regulated network utilities: evidence from EU telecoms. *Industrial and Corporate Change*, Vol. 2, Number 1, pp. 31-71, **and**, Cambinini, C., Fumagalli, E. and Rondi, L. (2016). Incentives to quality and investment: evidence from electricity distribution in Italy. *Journal of Regulatory Economics*, Vol. 49, pp. 1-32.

[27] There is a large academic literature on how dynamic effects play a significant role on investment models in utilities and other areas by including the effect of the lagged dependent variable or the lagged investment/enhancement expenditure. For example, Nardi (2012) proposes an empirical analysis to asses if unbundling measures are related to the increase of grid investments focusing on 14 UCTE countries between 2001 and 2010. The author proposes a dynamic panel data model of interconnections investments. **Reference**: Nardi, P. (2012). Transmission network unbundling and grid investments: Evidence from UCTE countries. Utilities Policy. Vol. 23, pp. 50-58. Poudineh and Jamasb (2016) develop a model that considers the main determinants of investment under incentive regulation in the Norwegian electricity distribution network. Their dynamic model includes the lag of investment to control for the cyclical behaviour of investment. Large investment projects may take multiple years, so spells of high investments rates are followed by spells of zero investments, for example. Their main result is that due to the dynamic nature of investment decisions, large part of the variation in investments of the firms is explained by investment rates in previous period. The analysis is applied to 129 electricity companies in Norway between 2004 and 2010 using a Bayesian Model Averaging approach. **Reference:** Poudineh, R. and Jamasb, T. (2016). Determinants of investment under incentive regulation: The case of the Norwegian electricity distribution networks. Energy Economics, pp. 193-202

instance, between 2010 and 2015, SRN became the first water company to implement a 100% metering policy across their region due to their critical position as a water stressed zone.

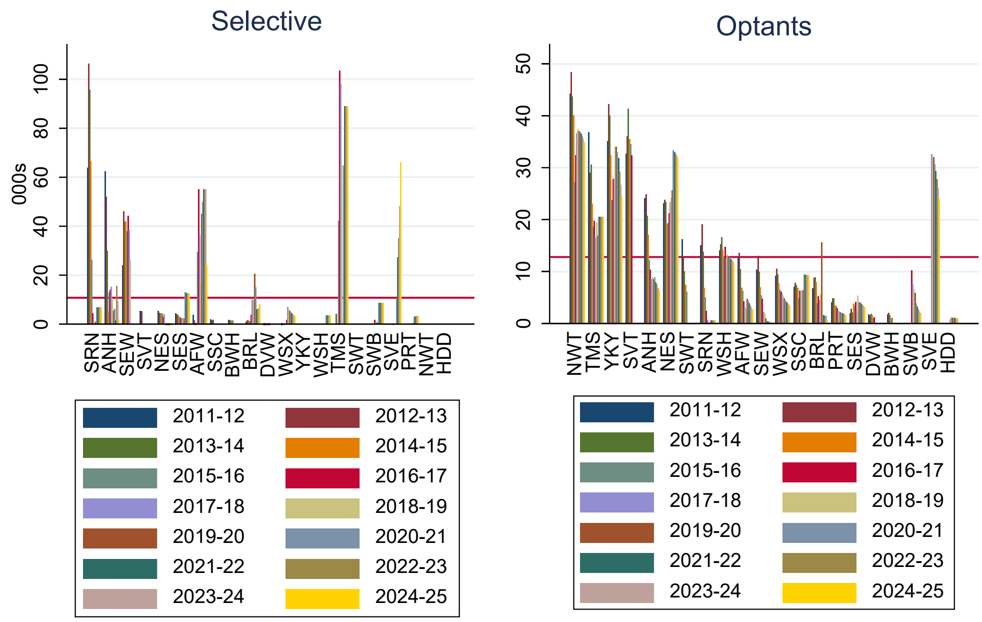
Figure 3 – Totex Metering Enhancement



Source: Economic Regulation, Thames Water

7.27 Another example of the different strategies implemented by companies is shown in Figure 4. The figure depicts the different levels of meters installed during AMP6 and AMP7 (e.g., selective or optant) reflecting the different priorities that companies are facing such as leakage reduction (a better control and understanding of the network using smart meters could help to reduce leakage). In addition, some companies are trying to understand, and provide incentives for, water consumption (per capita consumption-PCC) more efficient as is the case of SRN located in a water stressed zone.

Figure 4 – Meters Installed over AMP6 and AMP7



Source: Economic Regulation, Thames Water.

Ofwat PR19 Metering Enhancement Modelling and Static Panel Approach as an extension

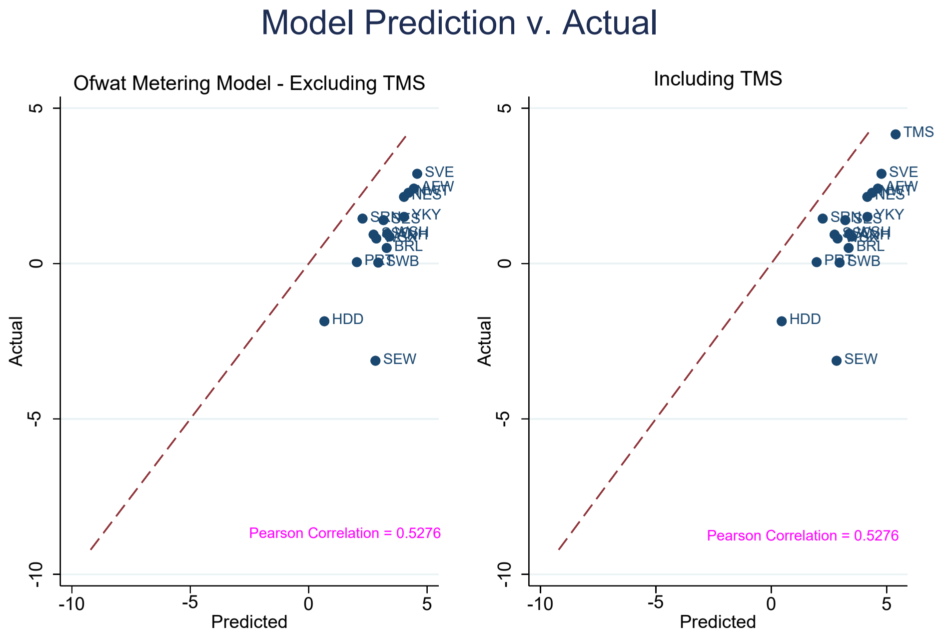
7.28 In this section, we introduce a summary of the PR19 FD approach used by Ofwat on metering enhancement modelling and explain how this approach shows some inconsistencies and weaknesses. We will also extend these models into a static panel data framework to see the potential for improvements from exploiting the characteristics of the panel data. In the following section we introduce the advantages of Dynamic Panel Data models.

7.29 A brief summary of Ofwat's approach to modelling metering expenditure and key assumptions is presented as follows:

- Ofwat has used a unit cost model based on the forecasted totex in metering expenditures submitted by companies for the period 2018 to 2025 (e.g., 7 year period).
- The main and only cost driver of the unit cost model is the combined number of optant and selective meters.
- The model is approached as a cross-sectional linear regression model at the levels and log specification.
- Ofwat aggregate totex by adding all years of the seven-period time to obtain a single observation for each company. Similarly, an aggregate of all optant and selective meters is created to obtain the total number of new meters for the seven-year period for each company.
- The final modelling outcomes face an efficiency challenge.

- Deep dive is applied for those companies where that modelling outcomes produce a material gap between Ofwat's forecast and companies' business plans.
- Thames Water (TMS) is excluded from the initial linear regression model as Ofwat consider TMS as an outlier without any empirical/test evidence of this; however, the estimated coefficients are used to create an approximate mimic calculation of meters outside London.
- Ofwat's metering models explicitly exclude a control for meter technology.
- There is no consistency on the allowance prediction calculations. Ofwat use a time framework of seven years, aggregated as a single cross-sectional model and use the estimated coefficients derived from this seven-year aggregation to a period that only uses five years (e.g., AMP7). Basically, it imposes a slope that does not belong to the initial set of observations used to estimate the original model.
- Finally, Figure 5 analyses the fit of the logarithmic model on metering. The chart depicts the 45-degree line for perfect correlation that indicates a good fitness of the model. The correlation between actuals and predicted values is significantly low (0.57) with or without Thames Water (TMS). Ofwat claims that TMS is an outlier but the right-hand chart in Figure 5 shows no indication of this claim. In fact, there are other observations such as SEW and HDD that are significantly underestimated and causing a poor performance of the model. Overall the predictions are underestimated across the industry showing a significant weakness of the model.

Figure 5 – Model Prediction v. Actual (Ofwat PR19 Ln's Metering Model)



Source: Economic Regulation, Thames Water. Note: In this Ofwat's model metering version we exclude realloacations.

7.30 In the following analysis we focus on the logarithmic version of the metering enhancement model proposed by Ofwat. Table 1 presents the econometric results of the aggregate or cross-section approach taken by Ofwat at PR19 excluding (column OM_A) and including TMS in the analysis (column OM_A_TMS). All the modes in Table 1 are based on the period 2018 to 2025.

Table 1- Ofwat Metering Models and Extensions

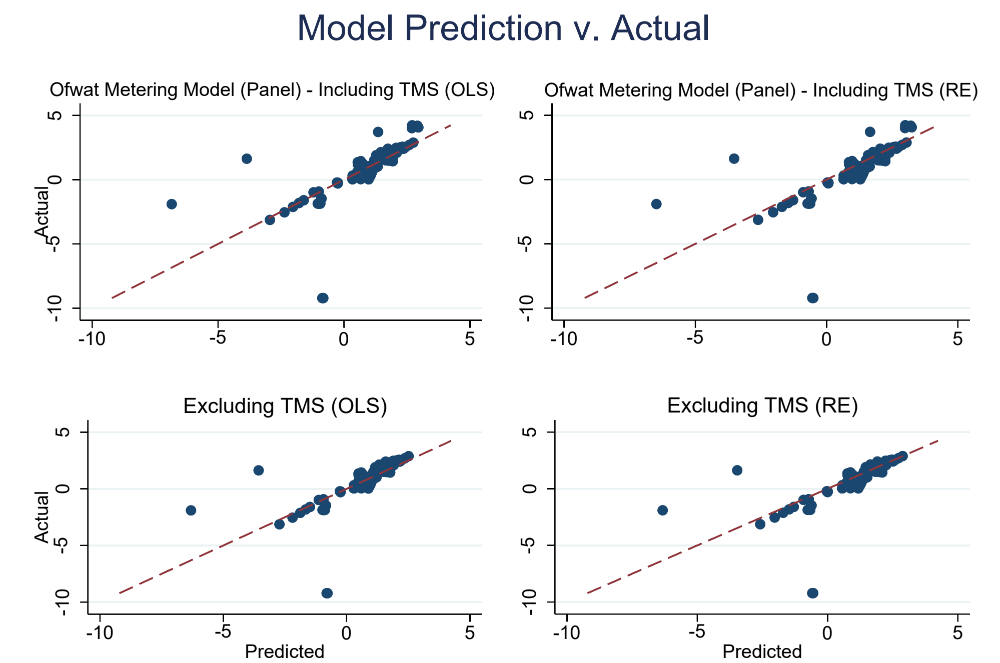
Ofwat Metering Enhancement Models and Extensions (Aggregated (A) and Panel (P) Versions)

	OM_A b/se	OM_A_TMS b/se	OP1T_OLS b/se	OP2T_RE b/se	OP1_OLS b/se	OP2_RE b/se
ln_agg_meter	0.992*** (0.05)	1.094*** (0.09)				
ln_meters			0.834*** (0.20)	0.828*** (0.27)	0.767*** (0.19)	0.800*** (0.28)
Constant	-1.414*** (0.23)	-1.835*** (0.38)	-1.002* (0.58)	-0.685 (0.82)	-0.939 (0.57)	-0.724 (0.80)
R2_Adjusted	0.9524	0.9333	0.5302		0.4839	
R2_overall				0.5336		0.4879
Observations	16	17	137	137	129	129

Source: Economic Regulation, Thames Water.
* p<0.10, ** p<0.05, *** p<0.01

7.31 In these two cross-section models, we did not make any reallocations in order to be consistent with the panel data results. These models show a significant R^2 above 0.93 with or without TMS. However, as mentioned before, the predictability of the model is quite poor (as shown in Figure 5) with serious concerns about the effects of potential outliers. This result indicates a significant harm on the final allowances. The last four columns of the models presented in Table 1 are an extension of this analysis by using a static panel approach (no aggregation of the data). Columns OP1T_OLS and OP2T_RE are models that include TMS and modelled by pooled OLS and Random Effects (RE). The last two columns present the same results but excluding TMS from the regression. The models with TMS included and exploiting the characteristics of the panel (RE) yield higher R^2 and a more accurate prediction than the ones that exclude TMS (see models OP1_OLS and OP2_RE).

Figure 6 – Model Prediction v. Actual (Static Panel Models OLS and RE)



Source: Economic Regulation, Thames Water. Note: In this Ofwat's model metering version we exclude realloacations.

7.32 However, Figure 6 shows again that few observations are causing a potential problem as they are likely to be outliers. The rest of the observations tend to be closer to the 45-degree line and to reflect a higher correlation between actuals and predicted values.

7.33 Table 2 summarises the predictions made by each of the models compared to the current Ofwat outputs on the log model presented in the first column of Table 2. If Ofwat had used the consistent approach of the prediction of the model, the allowances for this model would have been higher. By consistency we mean the prediction of the model over all the set of observations that the model is estimated and not to impose a change in the driver to only the aggregation of five years to make the prediction rather than the seven year aggregated period where the model estimations are based. The second and third column at least are consistent with the estimated coefficients[28].

Table 2 – Expenditure Predictions using Ln models

Expenditure Predictions using Ln models (Cross-Section v Static Panel Models), £m							
	Section Aggregate and Inconsistent Predictions	Cross-Section Aggregate and Consistent Predictions		Static Panel Models Predictions			
Company	Ofwat Metering PR19 model Ln (No TMS and Inconsistent)	Ofwat Metering PR19 model Ln (No TMS and Consistent) (OM_A)	Ofwat Metering PR19 model Ln (With TMS and Consistent) (OM_A_TMS)	OP1T_OLS with TMS	OP2T_RE with TMS	OP1_OLS No TMS	OP2_RE No TMS
AFW	60	85	101	49	65	40	56
ANH	17	30	33	17	23	15	20
BRL	11	27	29	12	16	11	15
HDD	1	2	2	2	3	2	2
NES	38	56	64	34	45	28	39
NWT	42	68	79	36	49	31	43
PRT	6	8	7	7	10	7	9
SES	19	24	25	19	25	17	23
SEW	0	17	17	1	1	1	1
SRN	9	10	9	10	13	9	12
SSC	11	15	16	12	16	11	15
SVE	75	98	119	59	80	48	68
SWB	14	19	19	14	19	13	17
TMS	112		219	89	119		
WSH	19	28	29	18	25	16	22
WSX	9	17	18	10	14	10	13
YKY	34	56	64	30	41	26	36

Source: Economic Regulation, Thames Water.

7.34 The last set of columns produce the predictions under a static panel approach where the RE models that exploit the characteristics of the data panel set suggest that the OLS cross-section or panel approach are yielding underprediction outcomes. In the next section we consider a potential way to tackle the irregularity/lumpiness of these types of investments/enhancement expenditures by extending the analysis into a dynamic panel framework.

Dynamic Panel Metering Modelling Approach: An Example

7.35 In this section we explore an alternative approach that allows us to capture the irregularities or lumpiness of the investment/expenditure on enhancements. We present the analysis in two parts. Firstly, we investigate the dynamic effect of investment/enhancement expenditure based on historical data (2011-12 to 2017-18) showing the persistent and significant effect that this driver has in the models and secondly, we extend the analysis using only the future values of the panel (2018-19 to 2025-25) as has been proposed by the current PR19 assessment of the metering enhancement case. Finally to highlight the importance of dynamic effects in these types

[28] As a simple way to explore, the totals produced by the consistent models can be divided by seven years and then multiply the yearly average by five to get a consistent outcome with the estimations of the models. By doing this, the outcomes are still higher than the ones produced by Ofwat. This piece of analysis/example on the calculation of the allowances is to illustrate the potential weakness and underestimation of the final allowances and the significant harm that companies are facing in this enhancement case.

of expenditure and its implications on the general performance of the models we can follow Bond (2002)[29] that stays that '*even when coefficients on lagged dependent variables are not of direct interest, allowing for dynamics in the underlying process may be crucial for recovering consistent estimates of other parameters*'.

Historical Dynamic Panel

7.36 In this section we present the main results of adding the dynamic effect of enhancement across different model specifications ranging from OLS to RE and Fixed Effects (FE). The mathematical expression of the dynamic panel data model is written as follows (this is independent of the way the models are estimated by OLS, RE or FE):

$$y_{it} = \delta y_{i,t-1} + x'_{it}\beta + u_{it}$$

7.37 Where δ captures the effect of the dynamic component of adjustment of previous levels of investments/enhancement expenditures calculated in the lagged variable $y_{i,t-1}$, x'_{it} contains all other exogenous drivers such as the scale controls like meters installed (e.g., selective, optant) or the different types of technologies on meters installed (e.g., AMI (Advanced Metering Infrastructure) or AMR (Automatic Meter Reading)) and u_{it} is the error component defined as $u_{it} = \mu_i + v_{it}$, where μ_i is the unobserved time-invariant heterogeneity of the firm and v_{it} is the random noise both to be assumed i.i.d.

7.38 Dynamic Panel Data Models estimated by OLS are biased and inconsistent by construction. Since the dependent variable $(y_{i,t})$ is a function of the unobserved time-invariant firm heterogeneity effect (μ_i), it immediately follows that the lagged dependent variable $(y_{i,t-1})$ is also a function of μ_i, hence it will be correlated with the error term (u_{it})[30]. Similarly, the within and GLS estimators for the Fixed and Random Effects models in a dynamic panel model approach are also biased and inconsistent[31].

7.39 Table 3 present the results on a historical dynamic panel data set framework for enhancement metering (2011-12 to 2017-18). The first two columns present the static version of the panel models (EM_COLSh and EM_CREh) estimated by OLS and RE. The rest of the table results show the dynamic version of the models by including the lagged effect of metering enhancement (L.ln_totex_metering).

[29] Bond, S. (2002). Dynamic Panel Data Models: A Guide to Micro Data Methods and Practice. The Institute for Fiscal Studies, CEMMAP working paper.
[30] See Baltagi, B. (2005). Econometric Analysis of Panel Data. John Wiley & Sons Ltd. Third Edition, or Arellano, M. (2003). Panel Data Econometrics. Advanced Texts in Econometrics. Oxford University Press.
[31] See Cameron, C. and Trivedi, P (2005). Microeconometrics, Methods and Applications. Cambridge University Press

Table 3 – Historical Static and Dynamic Panel Resutls

Historical Static and Dynamic Panels

	EM_COLSh b/se	EM_CREh b/se	EM_OLSh b/se	EM_REh b/se	EM_FEh b/se	EM_ABh b/se	EM_BB1h b/se
ln_meters	0.457**	0.457**	0.213	0.209*	0.206**	0.223**	0.309***
	(0.20)	(0.20)	(0.14)	(0.12)	(0.09)	(0.09)	(0.10)
L.ln_totex_metering			0.725**	0.640**	0.180	0.049**	0.614**
			(0.26)	(0.29)	(0.13)	(0.02)	(0.23)
Constant	-0.902	-0.902	-0.083	-0.137	0.412	0.565	-0.552**
	(0.67)	(0.67)	(0.16)	(0.33)	(0.28)	(0.41)	(0.24)
R2_Adjusted	0.0556		0.7419		0.3328		
R2_overall		0.1094		0.7594	0.6364		
Observations	124	124	102	102	102	82	102

Source: Economic Regulation, Thames Water. Note: AB=Arellano-Bond Estimator, BB=Blundel-Bond Estimator. All models include Time Dummies Year Effects.
* p<0.10, ** p<0.05, *** p<0.01

7.40 As mentioned earlier, dynamic models estimations by OLS, within and GLS estimators, for the pooled (EM_OLSh), Random Effects (EM_REh) and Fixed Effects (EM_FEh) models are by construction biased and inconsistent but provide information about the magnitude of the bias on the lagged dependent variable and its effects on other controls. The potential upward bias of the dynamic effect is provided by the OLS estimation (0.725) whereas the within estimation of the FE model provides the downward bias limit (0.180). Therefore, when correcting for the endogeneity issue the true value of the dynamic effect should be somewhere in between or not significantly higher than 0.725 or lower than 0.180. With respect to the other coefficient of numbers of meters installed (e.g., selective and optant, ln_meters) the results suggest that in the static models the estimation is biased with respect to the dynamic Random Effect model approach by a significant proportion (e.g., $\widehat{\beta_{Meters,RE\ Static}} = 0.457\ v. \widehat{\beta_{Meters,RE\ Dynamic}} = 0.640$). This result is an example of what Bond (2002) suggests on the effects on other parameters of the model.

7.41 In order to tackle the endogeneity issue presented in the previous models of Table 3, the Arellano-Bond estimator (columns EM_ABh and EM_BB1h) uses instruments to correct the issue by using information on the previous time periods, t-2, t-3, etc. Hansen test of instruments validation is not rejected for model EM_ABh (Arellano-Bond). However, the coefficient of the lagged variable seems to be unrealistic or too low. This could be explained potentially by weak instruments that could be caused by finite-sample biases[32]. The Blundell-Bond estimator (column EM_BB1) or system GMM provides an alternative to this issue by incorporating more informative moment conditions that reduces the bias dramatically on the last two columns of the table with more sensible results on what is expected (e.g., $\widehat{\beta_{Meters,BB\ Dynamic}} = 0.309$ and $\widehat{\beta_{lagged,BB\ Dynamic}} = 0.614$).

7.42 These results based on historical data, show how important it could be to use a more appropriate approach on estimating a consistent enhancement type of expenditure that allow us to control for the irregularities or lumpiness that are presented within and between companies. In this metering example, the results indicate a statistically significant effect of the lagged dependent variable in almost all the different specifications presented in Table 3 (in particular, the unbiased model EM_BB1h last

[32] See Blundell, R., and Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models, Journal of Econometrics, 87, pp. 115-143.

column on Table 3). This empirical evidence suggests how important is to control for this dynamic effect in this type of expenditures because omitting this dynamic control could also have significant effects on other coefficients. This omission can end up in underestimated predictions as the one currently used by Ofwat, jeopardising the performance of companies and service to customers. The next section will present a similar analysis but using the future values of the panel to mimic the approach used by Ofwat in PR19 and to highlight the potential areas to be improved and the difference in the econometric results.

Forward-looking Dynamic Panel

7.43 Similarly, as explained in the previous section, we carried out the same estimation procedures to understand the dynamic effect of the lagged dependent variable (e.g., lagged enhancement metering expenditures or investments in meters installation) under a dynamic panel approach using the values that companies have put on the Business Plans or forward-looking values on metering enhancement for the period 2017-18 to 2024-25 (same period used by Ofwat's models). This will allow us to have a more consistent and comparable results between the two approaches.

7.44 Table 4 shows the results of the static panel models OLS and RE (EM_COLS and EM_CRE) and all the biased estimations of the dynamic approaches OLS, RE and FE (see columns EM_olsD, EM_RED and EM_FED).

Table 4 – Static and Dynamic Panels Resutls (Biased)

Static and Dynamic Panels (stage 1: Biased Estimations)

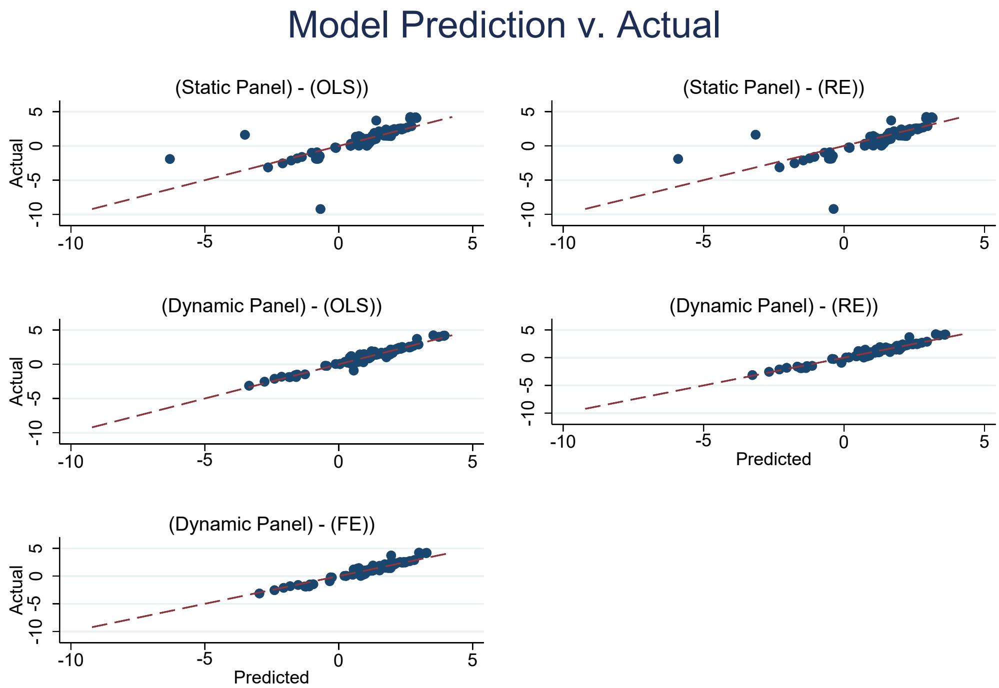
	EM_COLS b/se	EM_CRE b/se	EM_olsD b/se	EM_RED b/se	EM_FED b/se
ln_meters	0.784*** (0.17)	0.772*** (0.21)	0.484*** (0.12)	0.645*** (0.13)	0.681*** (0.15)
L.ln_totex_metering			0.576*** (0.15)	0.346** (0.16)	0.215* (0.10)
Constant	-0.817 (0.47)	-0.503 (0.66)	-0.760*** (0.15)	-0.884*** (0.19)	-0.831*** (0.26)
R2_Adjusted	0.5903		0.9581		0.8518
R2_overall		0.5934		0.9511	0.9400
Observations	135	135	115	115	115

Source: Economic Regulation, Thames Water.
* p<0.10, ** p<0.05, *** p<0.01

7.45 The biased estimations of OLS and FE under the dynamic setting, suggest that the estimated effect of the lagged dependent variable of enhancement metering program over AMP7 ranges between 0.215 and 0.576. In addition, these results also suggest a potential bias on the scale parameter of numbers of meters installed.

7.46 Figure 7 depicts the 45-degree line between fitted and actual values. The top two charts warn about potential outliers on the static panel results even after removing some potential outliers identified in Figure 6. These observations might cause potential issues on the estimations.

Figure 7 – Model Prediction v. Actual (Biased Models)



Source: Economic Regulation, Thames Water.

7.47 However, the dynamic biased models of OLS, RE and FE (see columns EM_olsD, EM_RED and EM_FED) successfully control for these remaining potential observations and the 45-degree line produces more accurate results (see Figure 7 dynamic panel models). The Pearson correlation of these models illustrated in the charts presented in Figure 7 are calculated on Table 5:

Table 5 – Correlations across models

	ln_tot~g
ln_totex_m~g	1.0000
xb_cols	0.6264
xb_cre	0.6264
xb_olsD	0.8877
xb_reD	0.8868
xb_feD	0.8435

Source: Economic Regulation, Thames Water

7.48 The improvement in the correlation coefficient between the static and dynamic models is substantial and we can easily see it on the predicted and actuals correlations as these are increased from 0.62 to around 0.88. Nevertheless, all these estimated results are significantly biased as explained in the previous section, regarding OLS, FE or RE effects models. To overcome the biased estimations presented in Table 4, we use the Arellano-Bond estimator (EM_AB) and the Blundell-Bond (EM_BB) estimator. The results of these dynamic models are presented in Table 6.

Table 6 – Dynamic Panels Resutls (Unbiased)

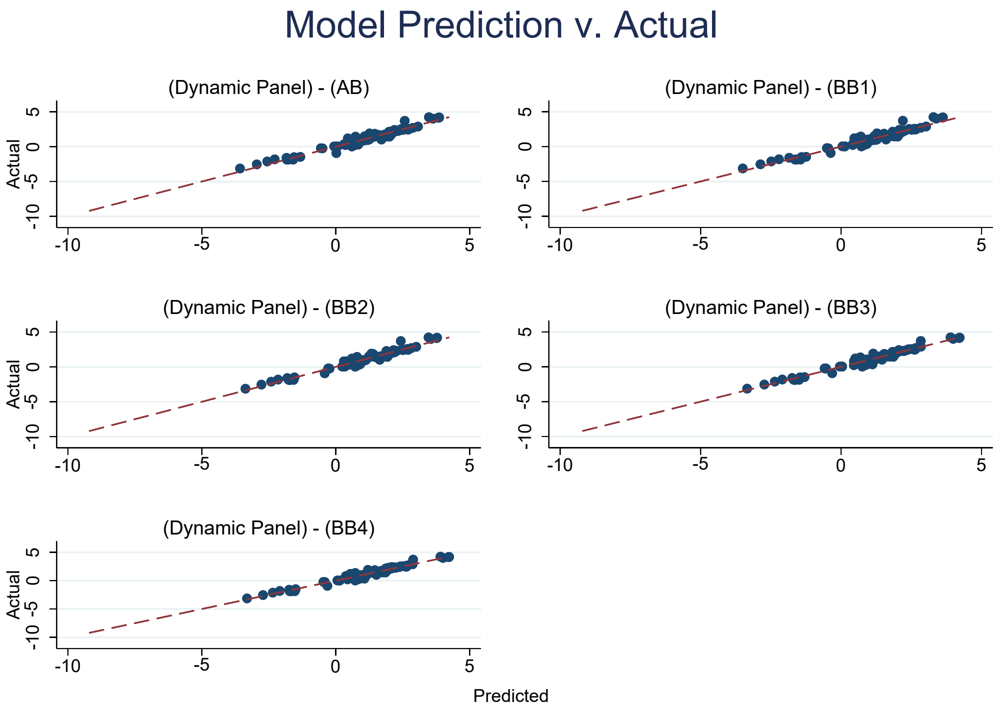
Dynamic Panels (stage 2: Unbiased Estimations)

	EM_AB b/se	EM_BB1 b/se	EM_BB2 b/se	EM_BB3 b/se	EM_BB4 b/se
L.ln_totex_metering	0.437*	0.298*	0.281*	0.286*	0.292**
	(0.24)	(0.15)	(0.15)	(0.14)	(0.14)
ln_meters	0.638***	0.728***	0.690***	0.707***	0.683***
	(0.16)	(0.12)	(0.12)	(0.12)	(0.11)
ln_density			0.183*		0.080
			(0.10)		(0.08)
ami				0.806***	0.689***
				(0.19)	(0.16)
amr				0.144	0.096
				(0.11)	(0.10)
Constant	-0.983***	-1.051***	-2.258***	-1.115***	-1.603**
	(0.18)	(0.15)	(0.74)	(0.19)	(0.61)
AB_Autocorr_order2	-1.605				
AR1_p_value		0.2712	0.3286	0.2634	0.3000
AR2_p_value		0.141	0.142	0.130	0.124
Hensen_Test_Overid~f		0.995	0.936	0.984	0.952
Number_Instruments		6.000	7.000	8.000	9.000
N	98.000	115.000	113.000	115.000	113.000

Source: Economic Regulation, Thames Water. Note: AB=Arellano-Bond Estimator, BB=Blundel-Bond Estimator
* p<0.10, ** p<0.05, *** p<0.01

7.49 The first two columns in Table 6 present the results for the EM_AB and EM_BB1 models. Both models show a significant effect of the lagged dependent variable. The scale effect (e.g., meters) is slightly lower for the dynamic panels presented in Table 4 (e.g., EM_RED and EM_FED) when compared to the results in Table 6, indicating a slightly marginal downward bias. The lagged dependent variable suggests a significant improvement on the estimations presented on Table 6 ranging between 0.215 and 0.576 as suggested by the OLS and FE models presented in Table 4.

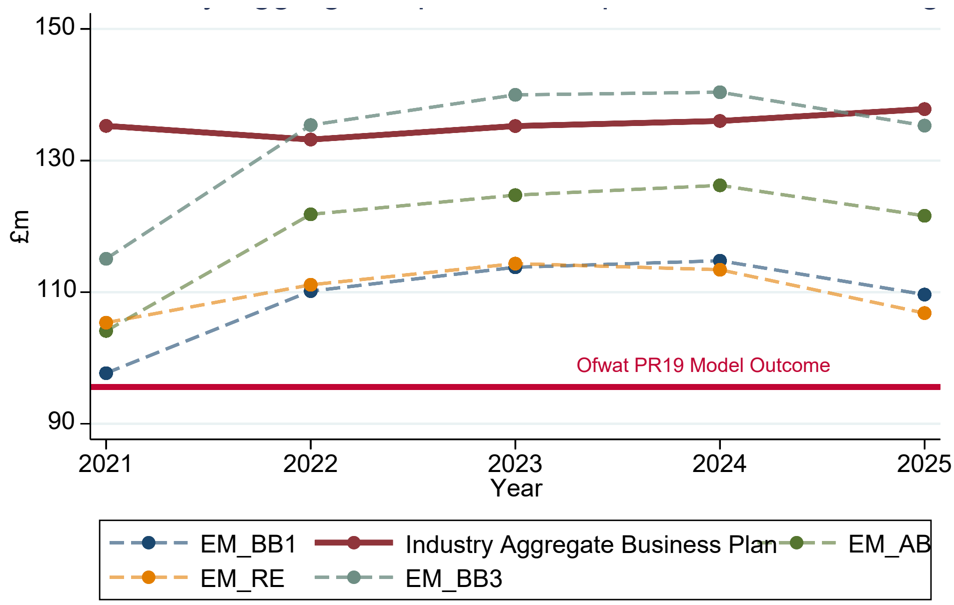
Figure 8 – Model Prediction v. Actual (Unbiased Models)



Source: Economic Regulation, Thames Water. Note: AB=Arellano-Bond Estimator, BB=Blundel-Bond Estimator

7.50 Figure 8 presents the correlation between actual and predicted outcomes from all the unbiased dynamic panel estimations. For all models, the correlations are between 0.80 and 0.87, presenting a consistent and better fit of the models. We have also extended the analysis by adding density (see model EM_BB2) and technology (see model EM_BB3) as other potential drivers that help to explain the results. We construct a technology meter variable to mitigate the effect of omitting this driver and to move away from Ofwat's assumption of not including any technology parameter in the models. For example, model EM_BB3 introduces the effect of technology represented by AMI and AMR meters. All these unbiased estimations are examples on how the model predictability is improved by controlling for the right dynamic patterns. Dynamic panels help us to avoid attempts explored in the past when modelling enhancement, such as moving average calculations that smooth the original data but adversely affect the consistency of the totex or botex identities (see PR14 assessment as an example).

Figure 9 – Industry Prediction Expenditure Aggregates on Enhancement Metering



Source: Economic Regulation, Thames Water. Note: Ofwat outcomes are divided by the total number of years in AMP7.

7.51 Finally, in terms of prediction, the outcomes of model EM_BB3 at the industry level is more in line of what is being requested by the industry in the business plans (see Figure 9), reflecting the relevance of the meter technology on the final outcomes of the model. Moreover, the effect of technology suggests a significant statistically effect on the enhancement metering expenditures (see AMI coefficient, for instance) which supports and provides empirical evidence on controlling for this parameter. Figure 9 also puts in context the prediction of different models presented across this section. It shows the potential underestimation of the current Ofwat allowance predicted by the cross-sectional model (see horizontal red line in Figure 9)[33].

7.52 The rest of the models such as EM_BB1 or EM_AB which are the product of consistent estimations also show significant higher outcomes in terms of the allowances predicted. These results suggest that Ofwat's approach can be substantially improved if the right econometric methodology is chosen. The results also suggest that significant econometric biases are having a substantial material impact on the industry regarding metering enhancement expenditures. We believe that most of the enhancement expenditures (when appropriate) should be modelled or at least explored using dynamic panel data models as an alternative to what has been proposed in the past PR14 and PR19 reviews. This approach has the potential to improve the assessment of these expenditures and to bring more reliable and objective outcomes, that will be beneficial for customers, the environment and companies. The dynamic approach is a promising technique in controlling for the irregularities/lumpiness of enhancements expenditures.

[33] We have divided the total allowance produced by this model by five, to represent the yearly average produced by this model, as the cross-sectional model can't produce a yearly prediction being panel models.

D Uncertainty

7.53 Using Yardstick Competition/indirect competition/benchmarking (see Baiman and Demski (1980) or Holmstrom (1982) as the initial proposers on yardstick competition) is the regulatory approach to reduce informational asymmetries in the industry between the regulator and the companies. For an application of this theory on regulation, the first attempt was made in the article by Shleifer (1985)[34]. One of the key assumptions in the article regarding the theoretical model that produces first-best and second-best outcomes is that firms are risk-neutral operating in an environment without uncertainty. In this article the theoretical predictions are taken into practice using econometric techniques that can be applied when firms are not entirely identical due to heterogeneities. However, this model developed in the eighties assumes no uncertainty and forces the current econometric approach of Ofwat to fit with the assumption of no uncertainty. We believe that the cost assessment process should consider or control for some degree of uncertainty within or without the econometric models.

7.54 To explore the effect of uncertainty, we will need to control for risks/uncertainties in order to update the current theoretical assumption of no uncertainty into a more realistic scenario given the current environment that we live nowadays (e.g., current health crises, more severe climate shocks, etc.). From the econometric point of view there are different examples and approaches on how to start thinking about this issue. For example, Torres et.all (2005)[35] treat the output (e.g., water distributed) as endogenous in order to capture the uncertainties that are surrounding the cost function thorough the use of the *expected* output rather than the *realized* output (e.g., by output we mean water delivered, number of customers, length of mains). An excellent description is found in Moschini (2000)[36] that states:

7.55 "*a problem then arises when the production technology is inherently stochastic. Such a case is very important in agricultural and environmental production models, where climatic and pest factors outside of the producer's control affect realized output in a nontrivial fashion. When producers make their input choices prior to the resolution of this production uncertainty, the standard cost function specification (which is conditional on the realized output level) is not relevant. In this setting one should instead study input choices conditional on expected output level, i.e., estimate the structure of an 'ex-ante' cost function*".

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[34] See Baiman, S. and J. Demski. (1980). Economically optimal performance evaluation and control systems. Journal of Accounting Research. Or, Holmstrom, B. (1982). Moral Hazard in teams. Bell Journal of Economics, and Shleifer, A. (1985). A theory of Yardstick Competition. The RAND Journal of Economics. Vol 16, No. 3, pp. 319-327.

[35] See Torres, M, and Morrison, P (2005). Driving forces for consolidation or fragmentation of the US water utility industry: A cost function approach with endogenous output. Journal of Urban Economics.

[36] See Moschini, G. (2000). Production risk and the estimation of ex-ante cost functions. Journal of Econometrics.

Thames Water