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Ongoing Efficiency Improvement at RIIO-ED2

Prepared for the Energy Networks Association

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Contents

Executive Summary

Ofgem has asked DNOs to propose an Ongoing Efficiency (OE) assumption to total expenditure (totex) as part of the electricity distribution price control due to begin in March 2023 (RIIO-ED2). The OE assumption should reflect the annual reduction in the required volume of inputs that an efficient DNO would be able to achieve while producing a given volume of outputs.[1] The Energy Networks Association (ENA) commissioned NERA to provide independent advice on the level of OE supported by the best available evidence.

Ongoing efficiencies are incremental gains in productivity that are achievable for a notional DNO that is already operating at the efficient frontier, due to technological progress. It is separate from catch-up efficiency improvements, which should not be included in the OE assumption for a given period.

The best available evidence supports an OE assumption of 0.3 per cent per annum across RIIO-ED2. This report surveys a wide range of evidence on historical productivity growth to identify the trends relevant to the OE assumption for RIIO-ED2. The main sources of quantitative evidence considered in this report are:

- Estimates of growth in total factor productivity in comparator sectors available from the EU KLEMS database for the years 1970-2007 using the Gross Output measure. Ofgem has referred to the EU KLEMS database in previous price controls, as have network companies in their submissions to Ofgem. The alternative measure to Gross Output, known as Value Added, measures the growth in total factor productivity relative to internal labour and capital inputs alone. Value Added estimates of productivity growth to measures only reflect the growth in businesses' productivity excluding energy, materials and services. We understand that Ofgem requires an OE assumption to apply to network companies' totex. We therefore rely on Gross Output measures alone in this report. Value Added measures are inconsistent with a requirement on totex, would result in a biased OE assumption, and are not suitable for use in the context of the RIIO-ED2 regulatory framework;
- Modelling of the efficiency improvements that DNOs have achieved from 2010/11 to 2019/20 estimated using a Törnqvist approach. NERA estimated this Törnqvist index directly from information provided by participating ENA members;
- Estimates of economy-wide productivity growth published by economic research institutions based on growth accounting approaches (GAA). This report considers long-term historical estimates and estimates based on data since 2010 separately to account for the reduction in productivity growth observed globally since the Global Financial Crisis (GFC) of 2007-2008; and
- Forecasts of productivity growth available from the Bank of England and the Office for Budget Responsibility.

Each category of evidence draws on a range of estimates across different comparator sectors, model specifications, and sources. Relying on a broad range of evidence in this way reduces

[1] Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Annex 2, Table 3.

the scope for subjectivity or "cherry-picking" and mitigates the impact of errors or inaccuracies embedded in any given estimate.

The mean estimated OE growth p.a. ranges from 0.1 per cent in the forecast evidence to 0.5 per cent for the EU KLEMS estimates, as shown in Table 1. Table 1 also shows the range of estimates within each category and summarises our assessment of each source of evidence based on four criteria set out in the columns of the table.

Table 1: Summary of the Evidence

Evidence	Captures trends in productivity for DNOs	Separates OE and catch-up	Objective and stable over time	Does not distort incentives	Range of estimates	Mean of estimates
EU KLEMS	◕	◕	◕	●	0.3-0.8%	**0.5%**
Törnqvist	●	◑	◕	◕	-0.1-0.4%	**0.2%**
Long-Term GAA	◑	◕	◕	●	0.3-0.5%	**0.4%**
Post-GFC GAA	◕	◑	◕	●	0.1-0.3%	**0.2%**
Forecasts	◔	◑	◑	●	0.0-0.3%	**0.1%**

Notes: Each criterion is assessed on a four-point scale from worst (quarter-full red) to best (full dark green).
Source: NERA analysis.

As can be seen from Table 1, the alternative sources of evidence have their relative strengths and weaknesses. For instance, as the only index that tracks inputs and outputs of DNOs directly, the Törnqvist index may be most effective at capturing trends in productivity for DNOs. However, comparable data was available for a shorter time period than the EU KLEMS data or long-term GAA. Volatility in productivity growth and systematic movements in DNOs' productivity relative to the efficient frontier may therefore be more likely to affect results from the Törnqvist indices we estimated. Given the differing merits of the different sources of evidence we present in Table 1, the most representative OE assumption is likely to draw on the range of evidence in Table 1.

The single OE assumption for RIIO-ED2 most consistent with the evidence presented in the Table above is 0.3 per cent p.a. This is the mid-point of the range of mean estimates for each of the evidence categories. 0.3 per cent p.a. is also the only assumption that is consistent with the range of estimates within every category of evidence. It is therefore the conclusion that is best supported by a balanced reading of the body of evidence. It is consistent with the range of estimates of DNO productivity improvements since the start of DPCR5 as estimated by the Törnqvist modelling.

The 0.1 to 0.5 per cent range of mean estimates defines the widest range of assumptions that could reasonably be derived from the evidence. An OE assumption outside of this range would be inconsistent with the sources of evidence presented in this report.

The 0.3 per cent OE assumption recommended in this report is lower than some assumptions used in previous price control reviews, although in line with recent international precedent. The difference is driven by three factors:

- We have presented new evidence not considered before in the form of the Törnqvist analysis, which indicates that the rate of achievable ongoing efficiencies for DNOs is lower than previously assumed;
- Some earlier price control reviews have erroneously placed weight on Value Added measures of productivity growth. These are inconsistent with a requirement on totex, and result in OE assumptions that are biased upwards. As such they are not suitable for use in the context of the RIIO-ED2 regulatory framework. Correctly using Gross Output measures results in a lower assumption; and
- We have reviewed recent evidence that economy-wide productivity growth has been slower in the decade since the Global Financial Crisis of 2008-2009 than in the historical period used in estimates of long-term productivity growth.

An assumption at the 0.1 per cent bottom of the range is consistent with the range of estimates from the sources based on more recent data (Törnqvist analysis, post-GFC GAA, forecasts). It could therefore be supported by placing more weight on current economic conditions. By contrast, an assumption at the 0.5 per cent top of the range is consistent only with the range of estimates within the two categories of evidence based on longer historical time series (EU KLEMS, long-term GAA). An estimate towards the top of the range would therefore require placing more weight on estimates of long-term trends.

The rate of OE that will be achievable during RIIO-ED2 may differ from the estimates in Table 1. These risks are, however, primarily to the downside. For instance:

- macroeconomic factors like the impact of Brexit and COVID-19 may depress technological and productivity growth in the general economy of which DNOs are part;
- DNOs may deliver efficiency gains as (unmeasured) quality improvements rather than cost savings;
- new requirements for RIIO-ED2 related to Net Zero and an expanded DSO role may result in increased expenditure given the traditional definitions of DNOs' outputs; and
- the estimates of historical OE may be inflated as a result of also capturing some catch-up gains.

On the other hand, there is no reliable evidence to support an OE assumption higher than the estimates in Table 1. This includes the unfounded innovation funding adjustment advanced by Ofgem at RIIO-T2/GD2. Therefore, based on the evidence available, a 0.3 per cent OE assumption could be a high target for DNOs for RIIO-ED2.

1. Introduction

The Energy Networks Association (ENA) has commissioned NERA to provide independent advice on the appropriate level of the ongoing efficiency (OE) assumption for RIIO-ED2.[2] The OE assumption should reflect the annual reduction in the required volume of inputs that an efficient DNO would be able to achieve while producing a given volume of outputs.[3]

The OE assumption is an input to the RIIO-ED2 price control review. RIIO-ED2 will regulate the allowed revenues of the 14 British distribution network operators (DNOs) from April 2023 to March 2028.[4] Ofgem has requested that DNOs provide a forecast of their OE assumption for ED2 as part of their Business Plans.[5] This will inform the cost savings from OE gains that all DNOs will be expected to deliver across the RIIO-ED2 period.

Ongoing efficiencies specifically relate to the incremental gains that are achievable for a notional DNO that is already operating at the efficient frontier. Ongoing efficiency improvements are increases in the productive possibilities of the industry resulting from factors such as technological advances. They are not a prediction of the improvements that specific DNOs will achieve.

OE is distinct from catch-up efficiency improvement and should be assessed and treated separately. Catch-up refers to efficiency gains achieved by companies that are not operating at the efficient frontier, as they move closer to the frontier. Any such companies would have additional scope to improve efficiency by emulating the practices of the best-performing companies. The scope for catch-up is modelled elsewhere in the RIIO-ED2 framework and should as far as possible not be included in the OE assumption.

The ENA has requested that NERA identify appropriate productivity metrics for the period 2021/22 to 2027/28. This period covers the remainder of RIIO-ED1 as well as the entirety of RIIO-ED2. Because productivity growth from ongoing efficiency gains is a long-term economic phenomenon, it is neither necessary nor possible to distinguish between the different years of the forecast period when considering most forms of evidence on OE.

This report therefore estimates an annual OE growth assumption covering the whole period. The report refers to the whole period from 2021/22 to 2027/28 when discussing the OE assumption for RIIO-ED2. Where relevant the report discusses the exact timing of productivity growth, for example in the context of the impact of the UK leaving the European Union and the impact of the COVID-19 pandemic.

The OE assumption that this report informs will be applied to DNOs' total expenditure within the price control framework (totex). It therefore consistently uses productivity measures calculated based on total cost measures of inputs. Using productivity measures that are not consistent with the cost base that the OE assumption will be applied to would result in errors,

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2 The scope of this report is strictly limited to the OE assumption. It does not contain any recommendations for other aspects of the RIIO-ED2 methodology.

3 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Annex 2, Table 3.

4 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Overview, Foreword.

5 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Annex 2, para. 4.16.

and in some cases bias, in the resulting OE requirement. The report explains this problem in detail for each type of estimate in the respective sections.

Ofgem has outlined several categories of evidence that DNOs could provide to support the assumption.[6] This report reviews all these categories of evidence as well as others to inform an OE assumption. The remainder of the report is organised into sections based on the categories of evidence. It proceeds as follows:

- Section 2 provides conceptual background and reviews regulatory precedent. It defines four criteria for assessing whether candidate methods are appropriate for setting an OE assumption. It explains the conceptual problem of observing DNO efficiency gains and introduces candidate approaches. It surveys and critically assesses regulatory precedent in Great Britain and internationally, and draws key lessons that inform this study;
- Section 3 presents evidence from growth accounting approaches to estimating historical productivity growth. This includes estimates from the EU KLEMS database, as well as estimates from institutional sources such as the Office for National Statistics and the Bank of England. It explains key methodological decisions and errors in Ofgem's use of growth accounting estimates in its determinations for RIIO-T2/GD2, including its decision to rely on unsuitable Value Added measures;
- Section 4 estimates the productivity improvements that DNOs have achieved from the start of DPCR5 in 2010/11 to 2019/20. The report uses data provided by DNOs and a Törnqvist modelling approach to derive new estimates of historical productivity growth in the DNO sector. This represents a new contribution of evidence beyond the sources used at past price control reviews. The estimates from the Törnqvist modelling both inform and provide a benchmark for the OE assumption for RIIO-ED2;
- Section 5 reviews and critically assesses evidence on the applicability of historical estimates of productivity growth as an OE assumption for RIIO-ED2. This includes evidence on whether current macroeconomic trends are the same as those during the sample periods used for the historical estimates. The section also assesses whether a range of factors could support an OE adjustment above or below the historical estimates. This includes arguments that have been advanced by British regulators, including a detailed assessment of the role of innovation funding;
- Section 6 summarises the available evidence and critically assesses each source against the criteria for an appropriate method. It presents this report's conclusions and recommendations;
- Appendix A describes the technical details of the Törnqvist modelling from Section 4.

6 Ofgem (22 April 2021), RIIO-ED2 Business Plan Guidance, para. 5.45.

2. Review of Precedent

This section sets out and reviews approaches to setting ongoing efficiency (OE) requirements that are common in regulatory decisions in Great Britain and in selected international jurisdictions. It is structured as follows:

- Section 2.1 sets out four criteria that an approach for setting OE requirements should meet;
- Section 2.2 explains the methods commonly used by regulators for setting OE requirements, and sets out the advantages and disadvantages of each method as measured against the criteria;
- Section 2.3 describes recent decisions by British economic regulators; and
- Section 2.4 surveys decisions on OE requirements for electricity distribution companies by regulators in Australia, the Netherlands, Germany, and Sweden.

Our review of regulatory decisions in this section is primarily descriptive. While we draw contrasts and describe key conclusions from the determinations, we defer critical assessment of regulators' approaches and decisions to Section 3.4 (on growth accounting methodology) and Section 5 (on the applicability of historical estimates to RIIO-ED2).

2.1. Criteria for Appropriate Methods

The purpose of an ongoing efficiency requirement is to adjust the allowed expenditure of network companies for improvements in cost efficiency that are achievable over time for even the most efficient companies. The potential for future OE improvements is not directly observable. Regulators therefore use different empirical approaches to assess the rate of OE that will be achievable for energy networks.

An approach to setting OE requirements should accurately identify the scope for cost efficiency improvement. However, it must also be feasible to implement as part of the broader price control framework. In practice, a high-quality approach will therefore meet four criteria:[7]

- **The approach captures trends in productivity for DNOs**: The approach must rely on data which may reasonably reflect the potential for reductions in DNOs' totex. Trends in productivity are both volatile and cyclical. Accordingly, the approach should capture long-term trends in productivity improvement to smooth noise in the dataset;
- **The approach separates productivity from catch-up**: The approach must identify ongoing efficiency improvement, and not catch-up efficiency improvement or non-replicable structural changes. An approach can achieve this either by using a method that separates OE and catch-up improvement, or by relying on a sufficiently long sample period given that OE will dominate the impact of catch-up over the long run;
- **The approach is objective and stable over time**: The approach must be stable over time in order to limit regulatory discretion and prevent the regulator 'cherry-picking'

[7] The criteria are not listed in order of importance.

between methods at each decision point so that allowed costs are systematically below companies' efficient costs; and

- **The approach does not lower incentives to reduce costs**: The approach should not have an adverse impact on consumers by reducing incentives for cost reduction and therefore resulting in higher costs or foregone benefits to consumers over time.

We use these criteria to assess candidate methods for determining OE requirements.

2.2. Main Estimation Methods

In practice, most utility regulators assess the scope for future OE based on estimates of historical productivity improvements. In this subsection we survey four common strategies used to estimate historical OE.

2.2.1. Growth accounting based on comparator sectors

Growth accounting is a macro-economic approach that attempts to explain output growth through the growth in disaggregated factors of production, i.e. input categories. This approach assumes that output produced is a function of inputs such as capital and labour. Growth in these factors will explain some of the growth in output over time. The method assumes that whatever variation in output is not explained by input growth is attributable to productivity growth. This assumption is the way growth accounting approaches (GAA) identify and estimate OE improvements.

GAAs often rely on measures of productivity growth in comparator sectors rather than direct estimates of OE for energy networks. As energy networks are regulated monopolies, they do not sell their services at market prices that reflect their value. Revenue-based measures of the value of outputs are therefore not appropriate for DNOs. Instead, regulators often use growth accounting estimates of the productivity growth in market sectors constructed from revenue-based output measures. Such data is available from the commonly used pan-European EU KLEMS database, which we discuss in Section 3, as well as national accounts and other sources.

Applying such estimates to the DNO sector implicitly assumes that the trend in productivity for DNOs is the same as in the selected comparator sectors. This assumption is hard to test without independent estimates of DNO productivity growth. It therefore also embeds a degree of subjective judgement when selecting comparators.

It is easy to iterate a GAA over time. It therefore has the potential to be a stable approach. It also does not distort DNO incentives as DNOs do not affect measured productivity for other sectors. While growth accounting does not distinguish between catch-up and OE, it can often rely on long time series that limit the impact of periods of catch-up efficiency improvement.

2.2.2. Sector-specific Törnqvist productivity indices

Törnqvist indices provide an alternative to growth accounting methods. A Törnqvist index is a methodology that can be used to calculate a measure of the volume of outputs for a firm or industry that is not based on revenues or market prices. It is possible to construct such an index for DNO output as a weighted average of variables that are measures of or proxies for the services that DNOs provide, such as customer numbers or volumes of energy delivered.

Combining Törnqvist indices for DNO outputs and costs yields an index of historical productivity growth that is specific to DNOs. The approach therefore has the potential to more accurately reflect trends in DNO OE than growth accounting measures derived from comparator sectors that may not be subject to the same trends. However, it also relies on the correct identification and weighting of variables that represent DNO outputs and that are available on a consistent basis as a sufficiently long time series.

Like the growth accounting approach, a Törnqvist index does not separate OE from catch-up. The necessary data is also often not available over a sufficiently long time period, which can increase the impact of periods of catch-up on estimates. Finally, while Törnqvist indices are based on DNO costs and outputs and companies therefore have some influence over them, each company will have limited impact on an index based on industry averages. The approach therefore has limited effect on DNOs' incentives.

2.2.3. Malmquist indices based on DEA

A Malmquist index is a measure of OE based on Data Envelopment Analysis (DEA). DEA is a non-parametric method for estimating the efficient frontier of an industry. Several European regulators use DEA for cross-sectional efficiency benchmarking of electricity and gas networks. Iterating a DEA analysis over several years yields a frontier that shifts over time. A Malmquist index calculates an OE estimate from the movements in the DEA frontier over consecutive years.

Malmquist indices have several theoretical advantages for identifying historical OE improvements. They are based on DNO productivity growth rather than comparator industries, and therefore produce bespoke estimates. A Malmquist index also distinguishes between OE and catch-up as it is based on shifts in the estimated efficient frontier rather than average productivity.

The theoretical advantages of the Malmquist approach come with practical problems. Unlike the Törnqvist approach it requires identifying the efficient frontier for DNOs through benchmarking. Malmquist indices therefore embed the problems and errors of the cross-sectional benchmarking approach.

The Malmquist approach also puts greater demands on the choice of output variables as it requires identifying variables that drive costs both across companies and across time. As with other DNO-specific measures, selecting outputs involves a degree of modelling discretion. It therefore has the potential for cherry-picking. Discretion also means that the approach may not be stable over time but can differ across regulatory periods.

Malmquist indices also have a potential to distort incentives for DNOs. The frontier in a DEA is determined by the subset of DNOs it determines to be efficient. If the number of frontier networks is small (and it could be as few as one), then each frontier DNO will have a substantial impact on the resulting trend estimate, distorting incentives for cost reduction. The distortion is greater the easier it is for a company to predict that it may set the frontier, for example if the modelling approach is stable over time.

2.2.4. Time trends from econometric cost assessments

A fourth approach to estimating OE is to use results from econometric benchmarking. If a regression analysis used for cross-sectional cost assessment contains a time trend variable, then this trend can be interpreted as the growth in average productivity in the sector.

The time trend approach is similar to Malmquist indices in that it can be integrated with efficiency benchmarking results, albeit based on regression modelling rather than DEA methods. It therefore has some of the same disadvantages as the Malmquist approach. The time trend may be biased if the cross-sectional benchmarking is misspecified.[8] This will be the case even for cost drivers that are appropriate for identifying differences across companies if these do not reflect output growth over time. Unlike the Malmquist approach the econometric time trend is based on all companies rather than just the frontier firm or firms.

2.3. Precedent in British Regulated Industries

This section reviews recent decisions on OE by British economic regulators. It focuses on decisions by Ofgem, Ofwat, and the Competition and Markets Authority (CMA), as the role of OE in the building-block frameworks used in these decisions is similar to the approach for RIIO-ED2. We also survey recent decisions by the Office of Rail and Road and the Civil Aviation Authority.

There are several common elements across the decisions, summarised in Table 2.1. In broad terms, the decisions are clustered around an OE requirement of 1 per cent p.a. Regulators have primarily relied on a GAA using EU KLEMS data to derive empirical estimates of historical OE as the numerical starting point. They have also consistently considered whether estimates are in line with the assumptions embedded in companies' business plans.

Table 2.1: Summary of OE Requirements in Recent GB Regulatory Decisions

Decision	Regulator	Primary Method	Cost Base	Requirement
ED1	Ofgem	Company Plans	Totex	0.8-1.1 per cent
T1/GD1	Ofgem	Growth Accounting (EU KLEMS)	Capex/ Opex	0.7 per cent/ 1.0 per cent
T2/GD2	Ofgem	Growth Accounting (EU KLEMS)	Capex/ Opex	1.15 per cent/ 1.25 per cent
PR19 Final Determination	Ofwat	Growth Accounting (EU KLEMS)	Totex	1.1 per cent
PR19 Final Report	CMA	Growth Accounting (EU KLEMS)	Totex	1.0 per cent

Notes: All numbers refer to final determinations except where otherwise noted.
Source: References provided in the body of the chapter.

8 Throughout this report, "bias" means statistical bias, whereby an approach produces estimates or results that in expectation are higher or lower than the correct value.

2.3.1. Ofgem has relied on EU KLEMS for its RIIO determinations

Ofgem has a track-record of using a growth accounting approach for setting OE requirements. It has specifically relied on EU KLEMS estimates for its determinations for GDNs and transmission companies both at RIIO-1 and RIIO-2.

Ofgem has also cited assumptions embedded in company business plans as support for its ongoing efficiency requirements. It noted companies' OE assumptions as evidence in favour of its determined requirements for both T1/GD1 and T2/GD2, in the latter case relying on a selective reading to make the evidence fit its decision. At ED1, Ofgem accepted the assumptions of the network companies.

This subsection surveys Ofgem's use of EU KLEMS estimates and the conclusions it reached for each price control, but not the detail of the methods used to derive estimates. We discuss the technical aspects of Ofgem's use of EU KLEMS in detail in Section 3.4.

RIIO GD1 and T1

Ofgem set different OE requirements for capex and repex on the one hand, and opex on the other, in its RIIO-GD1 and T1 Final Proposals. For both requirements it relied on estimates of productivity growth from 1970 to 2007 for comparator sectors from EU KLEMS, selecting construction as its "principal comparator".[9] Based on these estimates, Ofgem determined:[10]

- a requirement of 0.7 per cent p.a. for capex and repex, equal to the growth in value-added total factor productivity (TFP) in construction; and
- a requirement of 1.0 per cent p.a. for opex. This requirement did not correspond to any one estimate. Instead, Ofgem considered that it was line with the range of estimates for partial factor productivity estimates (i.e. either labour productivity or labour and intermediate input productivity) for a wider selection of comparator industries. It also noted that this assumption was "in line with network company assumptions".

RIIO ED1

Ofgem did not base its ED1 OE assumptions on EU KLEMS or other estimates of historical productivity growth. Instead it accepted the assumptions that companies had embedded in their business plans:[11]

> "An ongoing efficiency assumption was included by all DNOs in the costs submitted in their business plans. We have not adjusted these assumptions because we considered them to be reasonable as they were in line with independent information we referenced. So, costs savings of between 0.8 and 1.1% per year are included in the cost allowances."

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[9] Ofgem (17 December 2012), RIIO-T1/GD1: Real price effects and ongoing efficiency appendix, para. 3.3.

[10] Ofgem (17 December 2012), RIIO-T1/GD1: Real price effects and ongoing efficiency appendix, para. 3.3.

[11] Ofgem (28 November 2014), RIIO-ED1: Final determinations for the slow track electricity distribution companies: Overview, para. 4.42.

RIIO GD2 and T2

Ofgem adopted a similar approach for RIIO GD2 and T2 as at GD1 and T1, setting separate requirements for capex (including repex) and opex. In each case it relied on an EU KLEMS estimate of productivity growth for 1997-2016. Ofgem used value-added productivity growth for a weighted average of all industries, excluding non-market sectors, calculated by its consultant, CEPA.[12] In its Draft Determinations (DD), Ofgem proposed requirements for all network companies of[13]

- 1.2 per cent p.a. for capex and repex, calculated as the growth in value-added total factor productivity, plus a 0.2 percentage point adjustment for innovation funding; and
- 1.4 per cent p.a. for opex, calculated as the growth in the partial factor productivity of labour at constant capital, plus a 0.2 percentage point adjustment for innovation funding.

Ofgem adjusted its OE assumptions downward for the Final Determinations (FD) to 1.15 per cent for capex (including repex) and 1.25 per cent for opex. Ofgem motivated this change as assigning weight to gross output measures of productivity growth alongside value-added measures.[14]

While Ofgem relied on CEPA as support for its assumptions, its use of CEPA's EU KLEMS estimates was selective. CEPA presented 20 estimates for each of total factor and labour productivity, covering five comparator definitions, two sample periods, and both value-added and gross-output measures.[15] In its DD, Ofgem in each case chose to use the second-highest of the 20 estimates and then added an additional 0.2 percentage points to reflect alleged benefits from innovation funding.

Ofgem's OE assumptions in its FD also exceed CEPA's recommendation. In an updated report, CEPA recommended the following:[16]

> **"Therefore, in light of the levels of ambition set out by the companies, it seems reasonable to set 0.5% as a lower bound for the OE challenge for capex/repex and opex.**
>
> In setting the OE challenge, Ofgem should judge how much weight it places on the following factors that we consider would together support **a more stretching OE challenge of up to 0.95% on capex/repex and 1.05% on opex:"**

CEPA then listed seven different assumptions and arguments, including on the benefits of innovation funding, that "would together support" a set of targets 0.2 percentage points below the targets that Ofgem ultimately determined. Ofgem therefore assumed a higher

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[12] See CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 15.

[13] Ofgem (9 July 2020), RIIO-2 Draft Determinations – Core Document, para. 5.31-5.37.

[14] Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.22.

[15] CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, Tables 2.2 and 2.3.

[16] Original emphasis.
CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p. 7.

requirement than its own consultant thought could be supported even under a set of further assumptions that CEPA did not itself endorse.

Ofgem was also selective in its use of network companies' business plans as support for its proposals. It noted that the "most ambitious companies" (SGN and SPT) believed they could achieve OE on totex of around 1.0 per cent. While this was less than the FD's totex requirement of c. 1.2 per cent, the 1.0 per cent figure was also higher than the OE assumed by all other companies.[17]

Ofgem likewise noted that NGET and NGGT had assumed opex OE of 1.1 per cent as support for its 1.25 per cent requirement. It did not take account of the fact that the same companies had assumed lower efficiencies for capex, even further away from Ofgem's assumptions. Ofgem therefore not only relied on the highest estimates provided by any company (which was still less than its requirement), but also mixed and matched different estimates from the companies that were most optimistic for each individual category.

Ofgem further justified the higher requirements it set for GD2 and T2 through a series of consideration that were separate from both EU KLEMS and company business plans. This includes arguments

- that companies should "aim up"[18]
- that the industry's monopoly structure frees up management resources which will allow companies to achieve greater efficiency gains; and[19]
- that companies should achieve greater efficiency gains due to historical innovation funding.[20]

We discuss these arguments and their weaknesses in detail in Section 5. For the purpose of its T2/GD2 determinations, Ofgem considered that these arguments justify setting a requirement at the top of its consultant's estimated "reference range".[21] Ofgem further added the adjustment on top of the estimated range to reflect innovation funding.

All transmission and gas distribution network companies appealed Ofgem's FD for RIIO-T2/GD2. Several of the companies' disputed Ofgem's OE assumption. The matter has now been referred to the CMA.

2.3.2. Ofwat relied on EU KLEMS for PR19

PR14

At PR14, the determination for the AMP6 regulatory period for water and wastewater companies (from 2015 to 2020), Ofwat did not make an explicit allowance for productivity

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17 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.29.

18 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.21.

19 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.21.

20 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.26.

21 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.21.

improvements. Companies were required to submit in their business plans their own assumptions on productivity growth.

Bristol Water appealed Ofwat's determination to the CMA In its final determination for Bristol Water, the CMA applied an 'efficiency benchmark' of 1 per cent per year, to account for productivity growth, catch-up efficiency and the effect of RPEs.[22] The CMA did not arrive at this figure by separately determining an OE assumption, but its assessment took account of the efficiency challenge presented in Bristol Water's Statement of Case. The Statement of Case assumed 1 per cent annual productivity growth, based on analysis conducted by First Economics.[23]

PR19

Ofwat used EU KLEMS estimates from comparator sectors as the starting point for its PR19 FDs. In the FDs, Ofwat set an OE requirement of 1.1 per cent on wholesale base costs, as well as metering costs and some categories of enhancement costs.[24] This was a reduction from the 1.5 per cent requirement it proposed in the DDs.

Ofwat based its requirement in part on an estimate of historical productivity growth from its consultant, Europe Economics. Europe Economics proposed a 0.6-1.2 per cent range for the OE assumption.[25] It based this range on estimates for gross output TFP growth from EU KLEMS for different comparator sectors, sample periods, and data sets.

Ofwat considered a series of other arguments when setting the requirement at the top of the range proposed by Europe Economics. These include the following:[26]

- That it should assign some weight to value-added measures of TFP growth, which are systematically higher;
- That errors in measuring input quality improvements should enable DNOs to achieve greater productivity growth than that estimated by EU KLEMS; and
- That the totex and outcomes framework generates one-off efficiency improvements;

Ofwat did not explain how it quantified or weighted these factors to arrive at its conclusion. It did however state that the reduction from 1.5 to 1.1 per cent was in part intended to account for the increased rate of leakage reductions it expected the water companies to deliver.[27]

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22 CMA (6 October 2015), *Bristol Water plc - A reference under section 12(3)(a) of the Water Industry Act 1991 - Report*, para. 4.245.

23 CMA (6 October 2015), *Bristol Water plc - A reference under section 12(3)(a) of the Water Industry Act 1991 - Report*, paras. 5.74 and 5.75.

24 Ofwat uses the term "frontier shift" to mean productivity growth separate from RPEs, which we refer to as "ongoing efficiency". We continue to use "ongoing efficiency" when discussing Ofwat's determination as it is the same concept, and to avoid introducing unnecessary terminology.
Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 122.

25 Europe Economics (12 December 2019), Real Price Effects and Frontier Shift, Final Assessment and Response to Company Representations, pp. 6-7.

26 Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 122.

27 Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 63.

2.3.3. The CMA adjusted Ofwat's PR19 OE requirement downwards on appeal

Four companies have appealed Ofwat's FDs to the CMA for a redetermination. This includes appealing Ofwat's determined OE requirement. After receiving submissions from the appellants and from Ofwat, the CMA issued its Provisional Findings in September 2020.[28] It published its Final Report on 9 April 2021.[29]

The CMA decided to apply an OE requirement of 1.0 per cent p.a.[30] It derived a 0.7 per cent starting point from the EU KLEMS evidence using the following approach:

- It found that it was appropriate to base the requirement on the average productivity growth across "competitive sectors with similar activities to the water companies";[31]
- It chose to use a sample period based on the most recent full business cycle, which it identified as 1990-2007;[32]
- The CMA opted to use the average of the estimates for the comparator sectors rather than identifying the upper and lower bounds of a range as Ofwat did in its FD; and[33]
- The CMA also considered it would be inappropriate to rely on value-added estimates without a downward adjustment as "we apply the frontier shift to costs which are akin to intermediate inputs".[34]

The CMA therefore identified 0.7 per cent gross output TFP growth for 1990-2007 as the starting point for its analysis.[35] In its final determinations, the CMA adjusted the 0.7 per cent starting point upwards to 1.0 per cent, considering five further qualitative factors:[36]

- Assigning some weight to the higher value-added figures. While the CMA accepted that gross output estimates were the ones consistent with a totex benchmark, it considered that potential errors in gross estimates meant it should also consider value-added growth. We discuss this argument in detail in Section 3.1.3;

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28 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings.

29 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report.

30 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.616.

31 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.616.

32 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.533.

33 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.535.

34 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.545.

35 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.535.

36 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.616.

- Embodied productivity growth from increases in the quality of inputs, which it considered indicated scope for a higher assumption;
- That "water companies might be able to achieve some additional productivity growth due to the increased flexibility in the totex and outcomes framework", but that the potential was limited, temporary, smaller than in the previous period, and that there was "little robust evidence available of a substantial positive impact";[37]
- The slowdown in productivity growth observed in the wider economy since the Great Recession, which indicates that the historical evidence overstates the OE achievable during AMP7; and
- Companies' business plans, which the CMA considered consistent with a 1.0 per cent assumption.

The CMA also rejected several arguments presented by the parties, both for upwards and downwards adjustments:

- It did not make an adjustment, either upwards or downwards, to account for estimated historical productivity growth in the water sector;[38]
- The CMA found that there was insufficient evidence available to address any impact of COVID-19 through the OE requirement;[39]
- The CMA also considered that there was no need to adjust for any catch-up efficiency improvements that might be captured by the EU KLEMS estimates.[40] It reasoned that in the long run there is not scope for large and systematic inefficiencies in competitive sectors as inefficient firms would go out of business. We discuss this argument further in Section 3.2.2.

2.3.4. GB transport regulators assess efficiencies on a company-specific basis

We have also reviewed recent decisions by other economic regulators in Great Britain. This includes:

- The Civil Aviation Authority's (CAA) ongoing review (G7) of new commitments for Gatwick Airport's economic licence for the four-year period 2021/22 to 2024/25; and
- The Office of Rail and Road's (ORR) decision at the latest price control review for Network Rail, PR18, covering Control Period 6 (from 2019 to 2024).

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37 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.565.

38 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.570.

39 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.593.

40 CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.598.

The CAA's G7 review of Gatwick Airport's licence

The CAA is the UK's aviation regulator. As part of its role it regulates service standards and charges at UK airports that have significant market power, specifically Heathrow and Gatwick.

The CAA is currently developing new commitments that will be part of Gatwick Airport's licence for a four-year period starting in April 2021.[41] These commitments include restrictions on Gatwick's maximum charges, as well as requirements such as the level of new investments and the rebate system during the period.[42]

The CAA regulates Gatwick's charges on an RPI-X basis. The cap applies to Gatwick's published charges, which do not account for discounts that Gatwick may offer to airlines.[43] The X-factor does not specifically reflect ongoing efficiencies. Instead its role is to cover ongoing efficiencies, real price effects, changes to the operating environment and Gatwick's commitments, economies of scale, and other factors that drive overall costs.

In its February notice the CAA proposed to accept a commitment to a cap of RPI + 0 per cent.[44] The cap was not based on a bottom-up calculation or based on a bottom-up cost assessment. Instead it is developed through dialogue with Gatwick, and reflects the CAA's overall assessment of a level of charges that balances Gatwick's financial interests against those of airlines and passengers.[45] Since the CAA's regulation of Gatwick does not determine an OE requirement, it does not provide useful precedent.

The ORR and Network Rail's control period 6 (CP6)

The ORR is the economic regulator for Network Rail. Every five years it sets the level of access charges and the outputs that Network Rail must achieve throughout a regulatory period. Its most recent periodic review, PR18, determined funding for control period 6 (CP6), running from 2019 to 2024.[46]

The ORR's approach to regulating Network Rail is different in structure from the regulation of the energy and water networks. Instead of top-down or comparator-focused approaches (Network Rail has no peer companies in Great Britain), the ORR carried out a bottom-up assessment of costs for each of Network Rail's activities for PR18. This identified the overall scope for cost efficiencies for each activity. This contrasts with the RIIO approach of

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41 See CAA (February 2020), Economic regulation of Gatwick Airport Limited: notice of proposed licence modifications.

42 CAA (February 2020), Economic regulation of Gatwick Airport Limited: notice of proposed licence modifications, para. 4.

43 The CAA has instead indicated that it will monitor Gatwick's practice in offering discounts, with a willingness to take action mid-period if necessary.
CAA (February 2020), Economic regulation of Gatwick Airport Limited: notice of proposed licence modifications, para. 1.37.

44 The CAA has instead indicated that it will monitor Gatwick's practice in offering discounts, with a willingness to take action mid-period if necessary.
CAA (February 2020), Economic regulation of Gatwick Airport Limited: notice of proposed licence modifications, para. 1.37.

45 CAA (February 2020), Economic regulation of Gatwick Airport Limited: notice of proposed licence modifications, para. 1.23.

46 See ORR (31 October 2018), 2018 periodic review final determination: Overview of approach and decisions.

identifying requirements for different efficiency types (OE, catch-up, RPEs) that are applied top-down to all companies and across activities. PR18 therefore does not provide useful precedent for the efficiency requirement at RIIO-ED2.

2.4. International Precedent

This subsection surveys recent regulatory decisions on OE requirements across a selection of international jurisdictions, summarised in Table 2.2. We have selected this sample as each decision demonstrates a different empirical approach to estimating and setting an OE requirement. They therefore hold practical lessons for assessing the rate of OE relevant to RIIO-ED2.

Table 2.2: Summary of OE Requirements in Recent International Regulatory Decisions

Country	Sector	Year of Decision	Regulator	Primary Method	Cost Base	Requirement
Australia	ED	2019	AER	ED-Specific Törnqvist Index	Opex	0.5 per cent
Netherlands	GT	2020	ACM	GAA (EU KLEMS)	Total Costs	0.26 per cent
Germany	ED+ET	2018	BNetzA	Malmquist Index	Total Costs	0.42 per cent
Sweden	ED	2019	Ei	None	Opex	1 per cent*

Notes: The ACM's decision for the Dutch gas TSO GTS determined a single frontier shift parameter of 0.4 per cent rather than separately setting OE and RPE rates. The consultant (Economics Insights) estimates that the ACM relied on TFP growth of 0.26 per cent p.a. over the sample period underpinning its recommendation.
The BNetzA's decision for the electricity sector did not explicitly determine OE and RPE separately. The figure cited reflects the OE embedded in its estimates. The figure presented here does not take account of top-down downwards adjustment that the BNetzA applied when converting its estimates to a requirement.
Ei does not apply the 1 per cent requirement in addition to but instead of a catch-up efficiency requirement. The effective OE requirement is therefore lower than 1 per cent for most DNOs.
Source: References provided in the body of the chapter.

While the primary purpose of reviewing international precedent is to identify methodological lessons, we note that the requirements set by Ofgem for RIIO-1 and RIIO-2 are consistently more demanding than the assumptions in other jurisdictions:

- Ofgem set requirements of around 1 per cent for T1/GD1, ED1, and T2/GD2. This is higher than the assumption by regulators in all the jurisdictions we surveyed; and[47]
- Ofgem applies the OE requirement to a larger cost base (totex) than regulators in Australia and Sweden.

Ofgem's higher requirements are in part due to the fact that it has consistently set requirements towards the top of the estimated range of OE, as we describe in Section 2.3.1. Regulators in other jurisdictions, including Germany and Australia, have taken account of the

47 Because Ei does not apply the OE requirement on top of catch-up efficiency, the effective OE requirement is less than the headline 1 per cent for most companies. It has no impact at all on the allowed revenues of more inefficient companies. We describe this in Section 2.4.4.

uncertainty of estimates and set requirements towards the middle or lower end of estimated ranges.

Other regulators, including in Germany, have also found qualitative reasons for adjusting the requirements downwards. By contrasts, Ofgem has applied upwards adjustments to set requirements in excess of estimated historical OE, most recently for RIIO-T2/GD2.

2.4.1. The AER uses a DNO-specific Törnqvist approach

The Australian Energy Regulator (AER) began a review of its approach to forecasting productivity growth for electricity distributors (Distribution Network Service Providers – DNSPs) in 2018.[48] The AER specifically sought to forecast growth in opex productivity to use as an assumption when setting future revenue caps for DNSPs in the National Electricity Market (NEM).[49]

Törnqvist methodology

The AER's core approach for forecasting opex productivity growth was to construct a Törnqvist index for the multilateral partial factor productivity (MPFP) of opex.[50] It based the Törnqvist approach around its existing benchmarking models, developed by its consultants, Economic Insights (EI).[51]

The Törnqvist method was based around an econometric cost assessment. For each DNSP, EI regressed real opex, deflated by a composite labour, materials and services price index, on five cost drivers:

- Customer numbers
- Energy delivered (GWh)
- Ratcheted maximum demand (MW)
- Circuit length (km); and
- Customer minutes off supply.

EI calculated modelled costs attributable to each output by multiplying the estimated coefficients for each DNSP with the value of the output variable. Dividing the modelled cost for each output by total modelled cost then produced cost shares for each output. EI used the modelled cost shares as the value weights for each output when calculating the Törnqvist index of outputs which, combined with an index of opex, gives an index of opex MPFP.

The high-level design of the Australian Törnqvist study is close to our own approach for estimating historical productivity growth for the British DNOs, which we describe in Section 4. However, the detailed design of EI's econometric methodology contained several

[48] See AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors.

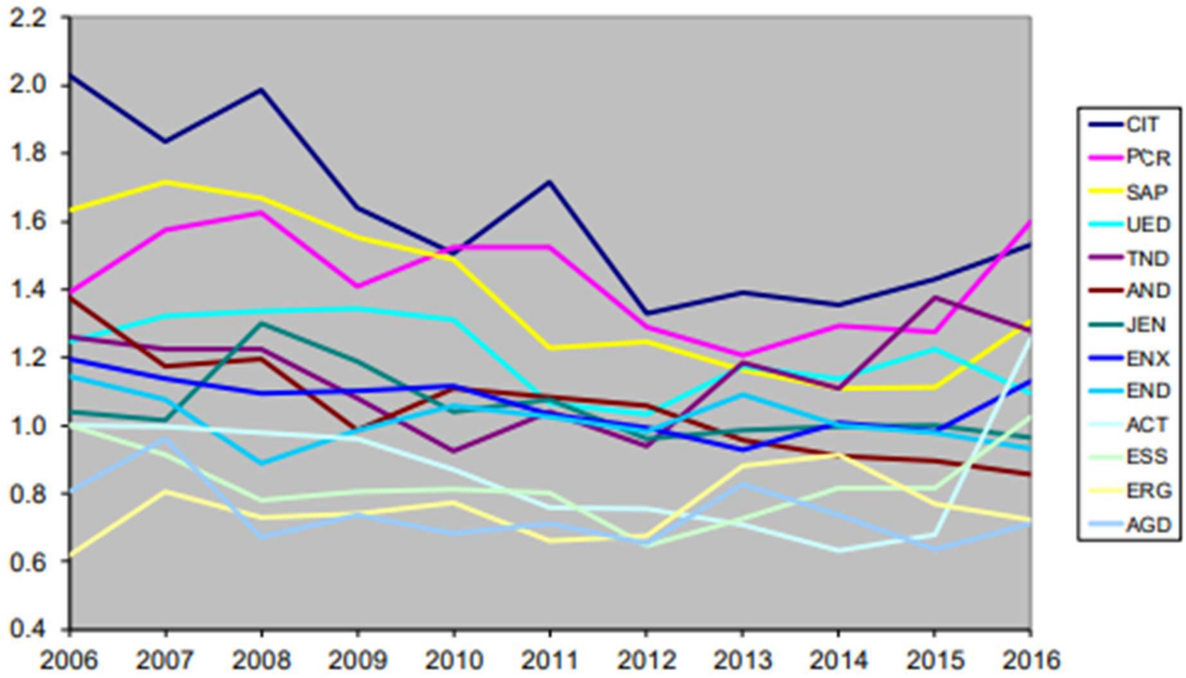
[49] The NEM is the grid and associated wholesale market that connects six eastern and southern states and territories.

[50] Partial factor productivity measures give the ratio of outputs to a one or more subcategories of inputs, in this case opex. By contrast, total factor productivity measures use the ratio of outputs to the sum of all inputs.

[51] See Economic Insights (9 November 2018), Economic Benchmarking Results for the Australian Energy Regulator's 2018 DNSP Annual Benchmarking Report.

errors and weaknesses.[52] Its opex MPFP estimates were therefore volatile both across time and across DNSPs, as shown in Figure 1.

Figure 1: EI's Estimated Opex MPFP for DNSPs, 2006-16



Source: AER.[53].

The AER applied a selective reading of the Törnqvist analysis in its draft decision. It considered shortening the sample period and only taking into account MPFP growth for 2012-16. It reasoned that the observed decline in productivity prior to 2012 likely reflected omitted factors, and therefore did not represent likely growth going forward:[54]

> "If we are going to use historic productivity growth to forecast we need to be satisfied that past productivity performance is reflective of what can be achieved going forward. However, we have not been satisfied that the past productivity growth that we have estimated, particularly for the period 2006 to 2012, occurred in 'business as usual' conditions. This reflects the significant new regulatory obligations that distributors were required to meet, and which required significantly increased opex, but with no change in measured output."

Given that its proposed sample period was only four years, the AER was concerned that estimates would include catch-up gains as well as ongoing efficiencies. Its draft determination therefore presented an estimate of MPFP growth that excluded four DNSPs

52 We explained the problems with EI's approach in a report commissioned by a group of DNSPs. NERA (20 December 2018), Assessment of the AER's Proposed Productivity Assumptions.

53 AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors, Figure 2.

54 AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors, p. 10.

that it believed were "materially inefficient".[55] Excluding these companies the AER estimated historical MPFP growth of 1.6 per cent. Drawing on this estimate and other evidence, the AER set a 1.0 per cent assumption in its draft decision.[56]

Final decision

Following criticism from DNSPs and other parties (including NERA), the AER amended its approach for the final determination. It expanded the sample period of the opex MPFP analysis to 2011-17, which reduced productivity estimates to a range of 0.35-0.97 per cent.[57]

The AER surveyed other sources of evidence alongside its Törnqvist estimates. This included evidence from the gas distribution sector. The AER considered that this was sufficiently similar to electricity distribution, but less subject to the unmeasured factors, and that gas could therefore provide a longer-term cross-check of its electricity sector estimates. The AER highlighted three such pieces of evidence as informing its decision:[58]

- The rate of productivity growth estimated in econometric models for the Australian electricity distribution sector, at 1.2-2.2 per cent;
- Time trends estimated in econometric models for gas distribution industry which the AER had relied upon in our previous gas distribution determinations, at 0.43-0.7 per cent; and
- Labour productivity forecasts for the utilities sector, at 0.3-0.7 per cent.

In its final decision, the AER determined an assumption of 0.5 per cent.[59] This figure was lower than the time trend in its econometric models for DNSPs, and within the lower half of the ranges estimated through the other methods.

Lessons

The Australian precedent provides an example of the Törnqvist approach in practice. While EI's regression analysis contains several pitfalls to avoid, the high-level design is close to our estimation strategy in Section 4.

The Australian experience also highlights the importance of external factors that affect costs but are not included in the regression analysis. The AER found large reductions in observed productivity in the years 2006 to 2012 because it could not measure the outputs that corresponded to the increased level of cost, namely performance against higher regulatory standards. Because the change in unobserved outputs was systematic over time, it biased results for this period.

Finally, the AER's final decision demonstrated a nuanced approach to deriving a point estimate from several sources of evidence to reduce over-reliance on a single technique. It identified several quantitative estimates using separate methodologies. The different sources of evidence were complementary, for example the AER used longer-term evidence from the

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55 AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors, p. 14.

56 AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors, p. 7.

57 AER (March 2019), Final decision paper: Forecasting productivity growth for electricity distributors, Table 2.

58 AER (March 2019), Final decision paper: Forecasting productivity growth for electricity distributors, p. 9.

59 AER (March 2019), Final decision paper: Forecasting productivity growth for electricity distributors, p. 10.

gas distribution sector alongside the shorter-term estimates for the DNSPs. Finally, the AER took account of the uncertainty of the estimates by setting a requirement towards the middle of the range of estimates available rather than picking an extreme estimate that would be more likely to be driven by errors.

2.4.2. ACM sets a requirement based on an EU KLEMS GAA

Framework and decisions

The Netherlands Authority for Consumers and Markets (ACM) is the economic regulator for the Dutch energy networks. As part of its regulatory framework it determines a frontier shift requirement, combining OE and RPEs. ACM's most recent method decision, covering the 2022-26 regulatory period for gas TSO Gasunie Transport Services (GTS), came out in January 2021.[60]

ACM determined a 0.4 per cent frontier shift for GTS's total costs.[61] As at past method decisions, a GAA using EU KLEMS data has been ACM's primary method for determining the OE component of frontier shift. For the 2022-26 period ACM relied on a study by its consultant, Economic Insights (EI).[62] Based on a GTS-specific weighting of comparator sectors, EI recommended a TFP assumption of 0.26 per cent.[63] Combined with RPEs estimated at -0.14 per cent resulted in frontier shift of 0.42 per cent p.a., which ACM adopted.

ACM's approach is an example of a GAA using EU KLEMS. The Dutch experience specifically demonstrates pitfalls for the choice and weighting of comparator sectors. ACM's 2016 decision on revenue caps for GTS and electricity TSO TenneT for 2017-21 became the subject of judicial review.[64] This included scrutiny of the selection of comparator sectors underpinning the ACM's decision on OE, based on a report by its consultant, Oxera.[65]

Weighting of comparator sectors

While the review found that the selected comparator sectors were appropriate, it concluded that the weighting of the comparators was not. The problem with the highest impact was the inclusion of telecommunications as a comparator. The estimated TFP growth in telecommunications was not only the highest across Oxera's comparators, as shown in Table 2.1, but in fact the highest of all Dutch sectors in the EU KLEMS data set. Since Oxera used an unweighted average of the growth across its comparator sectors, telecommunications accounted for most of the average TFP growth across the sample.

60 ACM (29 January 2021), Methodebesluit GTS 2022-26.

61 ACM (29 January 2021), Methodebesluit GTS 2022-26, para. 398.

62 EI (1 May 2020), Frontier Shift for Dutch Gas and Electricity TSOs.

63 EI (1 May 2020), Frontier Shift for Dutch Gas and Electricity TSOs, Table 8.4.

64 EI (1 May 2020), Frontier Shift for Dutch Gas and Electricity TSOs, p.30.

65 Oxera (January 2016), Study on ongoing efficiency for Dutch gas and electricity TSOs.

Table 2.3: TFP Growth by Comparator Sector in the Oxera Study

Sector	TFP (GO), two cycles, 1992–2008
Telecommunications	2.2%
IT and other information services	0.3%
Professional, scientific, technical, administrative and support service activities	-0.7%
Construction	-0.4%
Financial and insurance activities	0.3%
Transportation and storage	0.8%
Other manufacturing; repair and installation of machinery and equipment	0.6%
Electricity, gas and water supply	0.1%
Unweighted average (core set)	**0.4%**

Source: Oxera.[66]

According to the judicial review, the high weighting of the telecommunications sector introduced an error to the estimate because productivity trends in telecommunications have not matched those of energy grids. While telecommunications is also a network industry, it differs from energy networks in that it relies heavily on information and communications technology (ICT) inputs. The quality of ICT inputs increased rapidly across the sample period.

Improvement in ICT quality is a change to the inputs of the telecommunications sector, not an improvement the production process that converts inputs to outputs, and therefore should not be captured by TFP estimates.[67] However, EU KLEMS does not accurately measure changes in input (or output) quality. The estimated productivity growth in telecommunication was therefore likely overstated due to quality mismeasurement.

ACM sought to address the problem of weighting comparator sectors ahead of the 2022-26 regulatory period. It commissioned a report by Ecorys that estimates the appropriate weight for each comparator sector.[68] Ecorys found that the appropriate weight for both the telecommunications and the IT and other information services sectors was only 4 per cent each.[69] This indicates that these sectors were over-weighted in the Oxera study, biasing results upwards.

Lessons

The Dutch experience highlights two lessons for the OE assumption at RIIO-ED2. The first is that while estimates such as EU KLEMS attempt to control for embodied technical change, in practice some of the estimated TFP growth results from improvements in input quality. Mis-measured embodied technical change will be a more important driver of observed

66 Oxera (January 2016), Study on ongoing efficiency for Dutch gas and electricity TSOs, Table 6.1.

67 In technical terms, it is embodied rather than disembodied technical change.

68 Ecorys (15 January 2019), Wegingsfactoren voor frontier shift TSO’s.

69 Ecorys (15 January 2019), Wegingsfactoren voor frontier shift TSO’s, Table 1.1.

productivity growth in some sectors than in others and can exceed any input quality improvements for the network sectors.

Second, the judicial review's findings regarding the telecommunications sector is a lesson in selecting and weighting comparator sectors when using EU KLEMS data. Sectors that have superficial similarities to electricity networks need not experience the same productivity trends. Individual sectors can also contain important sources of measurement error. Placing excessive weight on individual sectors based on judgement or precedent therefore increases the potential impact of errors relative to a broad and balanced reading of the evidence. Finally, the Ecorys (2019) study derived a weighting for comparator sectors specific to energy networks. We consider this weighting as part of our EU KLEMS analysis in Section 3.2.5.

2.4.3. The BNetzA considers both Malmquist and Törnqvist measures

The Bundesnetzagentur (BNetzA) is the economic regulator of the German energy networks. It determines revenue allowances to reflect the economic and efficient costs of network companies, most recently for the third regulatory period (RP3) for the gas (2018-22) and electricity (2019-23) networks.

Framework for ongoing efficiency

The allowance for all costs except pass-throughs is subject to an inflation adjustment, i.e. an escalation factor. This escalation factor consists of two components: changes in the consumer price index, CPI, minus a productivity factor (PF) that combines OE and RPEs. The higher the PF, the slower is the escalation of the revenue cap during the regulatory period, all else equal

Prior to RP3, the Incentive Regulation Ordinance (ARegV) fixed the PF uniformly for electricity and gas grids at 1.25 per cent and at 1.50 per cent during the earlier RP1 and RP2 regulatory periods, respectively.

For RP3, ARegV requires the BNetzA to determine the PF according to scientific methods and based on network operator data covering the whole area of Germany and going back at least 4 years from the third regulatory period onwards. BNetzA commissioned a consultant to set out a methodology for determining the PF. Following its consultant's recommendations, BNetzA separately determined the PF for gas and electricity networks based on measures of the deviation of productivity growth in the respective grids sector compared to the general economy as well as the deviation of input price inflation in the grids sector compared to the general economy.[70]

RP3

BNetzA has relied on this approach in its decisions on the PF for RP3. Following its consultant's recommendations, BNetzA determines two candidate figures for the PF for each sector. These candidates rely on two alternative methods to measure productivity changes, the Törnqvist and the Malmquist indices. The methodologies to determine the Malmquist

[70] Under the assumption that the general economy is characterized by competitive price setting, the PF is given by the growth in TFP minus real price effects.

and the Törnqvist indices have been almost identical for the gas and the electricity sector, as they are based on a single report of the BNetzA's consultant.[71]

Following a consultation process that began in 2017, BNetzA set the PF for RP3 at 0.49 per cent for gas networks in February 2018 using on an OE assumption of -0.51 per cent. This figure was based on the Törnqvist index, whereas the Malmquist index had led to a figure of 0.92 per cent. In its decision, BNetzA proposed to use the lower bound of this range. BNetzA mentioned the importance of the PF for the network operator's business viability as its rationale as well as the fact that it is the first time for the BNetzA to determine the PF empirically.[72]

In November 2018, BNetzA has determined a PF for the electricity sector during RP3 that is based on the lower of the Törnqvist and Malmquist candidates as well. Unlike in gas, the Malmquist led to a lower figure of 1.35 per cent, whereas the Törnqvist led to a higher figure of 1.82 per cent. In the rationale for its decision, BNetzA stressed that it does not consider either one of the two index figures to have a clear methodological advantage over the other and that BNetzA considers the range of 1.35 per cent to 1.82 per cent as plausible.

Because the BNetzA determined the PF for the electricity grids based on its estimate using the Malmquist index approach, it did not separately estimate a TFP assumption and an input price assumption. Instead it estimated these jointly.[73] However, the BNetzA assessed average input price inflation as part of its Törnqvist approach. Assuming that the same rate of input price inflation is embedded in the Malmquist estimate, then the Malmquist estimate implicitly found historical TFP growth of 0.42 per cent.[74]

As in the case of gas, BNetzA acknowledged the importance of the PF for the network operator's business viability as well as the fact that it is the first time for the BNetzA to determine the PF empirically. Hence, BNetzA proposed to set the PF at the lower end of the range. Furthermore, BNetzA acknowledged that the 1.35 per cent figure markedly deviated from the 0.49 per cent in its gas decision. To avoid any unintended breaks between both sectors, BNetzA applied a haircut of one third to the Malmquist figure of 1.35 per cent, i.e. its final decision for the PF for electricity grids was 0.90 per cent during RP3.

Judicial review

The BNetzA's determinations of OE and RPEs have been subject to and upheld by judicial review. Following the decision on the PF for gas networks in February 2018, several network operators appealed at the Higher Regional Court (OLG) of Düsseldorf. Two appellants were selected as "benchmark cases" ("Musterverfahren") and were dealt with first. Their appeals proved successful in July 2019. The OLG Düsseldorf found that the PF as determined by the BNetzA was insufficiently robust against changes to the data period

71 WIK (10 July 2017), Gutachten zur Bestimmung des generellen sektoralen Produktivitätsfaktors.

72 The 0.49 per cent figure reflects an estimate of the growth in total factor productivity ("TFP") of the network industry of -0.51 per cent p.a., input price inflation of 0.35 per cent p.a. and CPI inflation of 1.35 per cent p.a.

73 The BNetzA found that the sum of TFP growth and input price inflation was 0.00 per cent on average across modelled cases and sample periods.
BNetzA Beschlusskammer 4 (18 November 2018), Beschluss BK4-18-056, p. 61.

74 The BNetzA estimated average input price inflation of 0.42 per cent using for its Törnqvist approach. Given that the sum of OE and input price inflation was 0.00 per cent, this implies OE of 0.42 per cent.
BNetzA Beschlusskammer 4 (18 November 2018), Beschluss BK4-18-056, p. 42.

underlying its calculation.[75] In addition, the OLG Düsseldorf disapproved of some of the BNetzA's input data (accounting depreciation instead of regulatory depreciation, yearly cost of debt instead of average cost of debt) and the weighting of certain intermediate results (network operators' benchmarking scores).

The BNetzA subsequently appealed the OLG Düsseldorf's decision. In January 2021, the Federal Supreme Court (BGH) revoked the decision of the OLG Düsseldorf and ruled that the BNetzA decision was lawful. The reasons for this decision have not been published yet. However, the BGH might have argued in favour of a wide discretion of the BNetzA.

Network operators also appealed BNetzA's decision to set the electricity PF at 0.90 per cent. The appeal against the electricity decision had been put on hold during the gas case at the BGH. Now that BGH has ruled on gas, we expect that OLG Düsseldorf will continue the proceedings on electricity and will reflect in its decision the reasoning behind BGH's re-instatement of the BNetzA's decision on gas.

Lessons

The BNetzA's approach to setting the PF for RP3 provides an example of both a Törnqvist method and a Malmquist method in practice. Given that it considers different types of analysis, the BNetzA's approach also holds lessons for best practice in interpreting contrasting forms of evidence. For RP3 it has taken a balanced or even cautious approach by setting the PF based on the lower of the two estimates from the two methods. This acknowledges the uncertainty in its empirical approach and avoids imposing unachievable targets on the networks based on measurement error.

2.4.4. Swedish regulator Ei sets a combined OE and catch-up requirement

The Swedish Energy Markets Inspectorate (Ei) is the economic regulator for the electricity distribution and transmission companies in Sweden. As part of its building-block framework it determines an OE requirement for each four-year regulatory period. Ei only applies the requirement as the annual rate of reduction in revenue allowances to cover controllable opex, i.e. operating costs excluding pass-through items.[76]

Ei set an OE requirement on opex of 1 per cent for the current regulatory period, RP3, which runs from 2020 to 2023. Ei did not use an economic or statistical method to estimate this requirement. Instead, it justified its decision as follows:[77]

> It is also reasonable to apply, as in the previous regulatory periods, a minimum efficiency requirement of one per cent per year, as this can be considered to correspond to the average productivity increase in the industry.

Ei's approach to the setting each company's efficiency requirement combines catch-up and ongoing efficiencies. Ei sets an annual catch-up requirement on opex for each company based on DEA benchmarking. Each company is subject either to the estimated catch-up

75 Oberlandesgericht Düsseldorf (2019), Beschluss vom 10.07.2019 - 3 Kart 721/18 (V).

76 Ei is currently considering whether to move to a requirement on total costs for future regulatory periods. Ei (February 2020), PM2020:01, Ökade incitament för kostnadseffektiva lösningar i elnätsverksamhet.

77 NERA translation. Ei (October 2019), Effektiviseringskrav för elnätsföretag – lokalnät. För tillsynsperioden 2020–2023, p. 14.

requirement, or the 1 per cent OE requirement, but not both. For all but the frontier companies, the 1 per cent determined OE therefore results in a smaller adjustment to revenues than a 1 per cent OE requirement would in the Ofgem framework that applies both catch-up and OE requirement to each DNO.

3. Growth Accounting Approach for Comparator Sectors

Growth accounting is a macro-economic method that estimates the growth in total factor productivity (TFP) as the growth in output over and above the growth in inputs. Section 2.2.1 described the high-level features of GAA. This section explains the technical details of using a GAA, and our estimates of OE using GAA methods. It proceeds as follows:

- Section 3.1 explains the key method decisions for constructing a GAA estimate and outlines the methods used by GB regulators that have relied on GAA estimates for past regulatory decisions;
- Section 3.2 derives GAA estimates from the commonly used EU KLEMS database;
- Section 3.3 cross-checks the EU KLEMS estimates against other growth accounting estimates for UK productivity growth;
- Section 3.4 explains errors and corrects misconceptions in recent Ofgem decisions based on EU KLEMS estimates, with a focus on the RIIO T2/GD2 determinations; and
- Section 3.5 summarises the evidence and draws conclusions.

3.1. GAA Methodology and Decisions

3.1.1. The growth accounting framework

Growth accounting productivity measures apply a framework drawing on work by Jorgenson and Griliches.[78] The framework is based on production possibility frontiers where gross output is determined by capital, labour, intermediate outputs, and technology. Each industry can produce a set of outputs, but must purchase a minimum volume of distinct intermediate inputs, capital, and labour to produce these outputs. The production function is given by:

$$Y = f(K, L, X, T) \tag{1}$$

where *Y* is an index of outputs, *K* is an index of capital service flows, *L* is an index of labour inputs, and *X* is an index of intermediate inputs, and *T* is available technology. The input and output indices, which are used to calculate TFP, are indices of physical quantities rather than indices of prices or unit costs.

Taking logs, and making other simplifying assumptions we can represent the shift in the production function as the expenditure-share weighted growth of input indices and technological change (TFP):

$$\Delta \ln Y_t = s_t^K \Delta \ln K_t + s_t^L \Delta \ln L_t + s_t^X \Delta \ln X_t + \Delta \ln TFP_t^Y \tag{2}$$

where s^i denotes the average share of input i in the nominal cost of total output, and the factor shares sum to unity (i.e. $s^K + s^L + s^X = 1$). This equation states that growth in the volume of output can be accounted for by growth in intermediate outputs, capital services, labour

[78] O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database", *The Economic Journal*, vol. 199, Issue 538 page F374.
The framework is: Jorgenson, D.W. and Griliches, Z. (1967), "The explanation of productivity change", *Review of Economic Studies*, vol. 34 (3), pp. 249-83.

services, and a measure of multifactor or total factor productivity (TFP). TFP is unobservable, and so it must be measured as the difference between the growth in the output index and the growth in the input indices, as can easily be seen by re-arranging equation (2).

In turn, each individual factor of production is calculated as an index of different input sub-types. For example, the EU KLEMS database calculates labour input as a quantity index of individual labour types, as follows:

$$\Delta \ln L_t = \sum_l s_{l,t}^L \Delta \ln L_{l,t} \quad (3)$$

where the term on the right-hand side represents the growth (Δ) in $L_{l,t}$, the hours worked by labour type *l*, weighted by the average share of each type *l* in the total value of labour compensation or total wage bill ($s^L{}_l$). The KLEMS database classifies labour into 18 different categories by educational attainment, gender and age.[79]

Growth accounting estimates are available from several government sources and international institutions. The EU KLEMS database has been used for past regulatory decisions in Great Britain and in other jurisdictions internationally. Ofgem has decided it will use EU KLEMS data to set the OE requirement for RIIO-ED2, and Section 3.2 surveys and critically reviews the evidence from EU KLEMS.[80] However, estimates are also available from organisations such as the Office for National Statistics, the Bank of England, the Office for Budget Responsibility, and the Organisation for Economic Co-operation and Development. Section 3.3 reviews these sources.

3.1.2. Choosing a sample

The first methodology decision when using GAA estimates of productivity growth is to define a sample. Since the estimates will inform an assumption of the ongoing efficiencies that will be achievable during RIIO-ED2, the sample should be relevant to current productivity trends in the electricity distribution sector. The sample should also include as much high-quality data as feasible to reduce the impact of measurement error. This means specifying the sample along three dimensions:

- **Country:** Estimates are available for the UK, but also other countries and for averages across countries (such as the EU28). This section uses historical UK estimates as these are most reflective of trends in the UK economy and therefore most relevant for ED2;
- **Period:** Estimates are available for different sample periods. There is a trade-off between using longer historical time series that capture long-run trends and maximise the available data to reduce the impact of measurement error, and using less but more recent data that may better reflect current conditions. Section 3.2.4 explains the approach of this section, which is to use long samples. Section 5 critically assesses whether these reflect current trends, and the extent to which the historical estimates are applicable to ED2; and
- **Sectors:** Estimates are available both for the whole economy and in some cases for individual sectors. There is a trade-off between using a narrow sample definition that

[79] O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database", *The Economic Journal*, vol. 199, Issue 538, p. F379.

[80] Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Annex 2, p. 32.

tries to identify individual comparator sectors that are relatively similar to electricity distribution, and a wide sample definition that covers the whole economy, all market sectors, or alternatively a set of many different comparator sectors. Section 3.2.5 explains the rationale behind the comparator sectors used for the estimates in this section in the context of the EU KLEMS database.

3.1.3. Relationship between gross output and value-added measures

The measures differ in their treatment of intermediate inputs

There are two different measures of productivity and productivity growth: Gross output (GO) and value added (VA). The measures differ in that they use two separate measures of outputs, but also two separate measures of inputs. The difference is in their treatment of intermediate inputs, i.e. inputs other than capital and labour:

- **GO**: Productivity measured as the ratio of all outputs to all inputs;
- **VA**: Productivity measured as the ratio of outputs after subtracting the value of intermediate inputs, to the sum of capital and labour inputs only.

In other words, GO measures include intermediate inputs in the cost base against which TFP is calculated. VA measures exclude intermediate inputs both from the measure of output and from the measure of inputs. In simplified algebraic terms, the productivity measures are calculated as follows:

$$GO\ TFP = \frac{Index\ of\ GO}{Index\ of\ (K+L+X)} \qquad VA\ TFP = \frac{Index\ of\ (GO-X)}{Index\ of\ (K+L)}$$

Where GO is gross output, VA is value-added, K is capital inputs, L is labour inputs, and X is intermediate inputs.

While GO and VA are different measures of TFP growth, they are not independent estimates. They can be calculated using the same data and rely on the same modelling assumptions. As the simplified equations above show, they simply combine the same components using a different calculation. There is therefore a set mathematical relationship between growth in GO TFP and VA TFP:[81]

$$\Delta GO\ TFP\ = \frac{VA}{GO} \times \Delta VA\ TFP\ \approx \frac{K+L}{K+L+X} \times \Delta VA\ TFP$$

Estimates of VA TFP growth will therefore always be higher (in absolute terms) than estimates GO TFP growth by a factor approximately equal to the inverse of the share of primary inputs in total inputs. As GO and VA measures of TFP growth in any given year are

81 This an approximation. To be precise, "gross output TFP growth rate is equal to the value added TFP growth rate multiplied by a simple magnification factor. The magnification factor is the share of primary inputs (capital and labour) in total input use multiplied by the ratio of the growth factor of primary inputs to the growth factor of all inputs". As the growth factors of both primary and all inputs are close to one, and their ratio is therefore also close to one, using the share of capital and labour in all inputs is a close approximation.
Calver, M. (2015), "On the relationship between gross output-based TFP growth and value added-based TFP growth: An illustration using data from Australian industries", *International Productivity Monitor*, vol. 29, p. 69.
See also OECD (2001), "Measuring Productivity, Measurement of aggregate and industry level productivity growth", *OECD manual*, p. 26.

scaled versions of the same estimates there are few advantages to one measure or the other in terms of accuracy. There is also no information added by using one measure in addition to the other, except that we could derive the share of intermediate inputs. GO and VA relate to different measures of outputs and costs. Which measure is appropriate in a given context therefore depends on whether the estimate will be used in a framework based on gross outputs and gross costs, or a framework based on value-added outputs and primary costs.

The difference between GO and VA estimates of productivity growth is abstract and mathematical. In practice it is analogous to the difference between two different ways of measuring a can of tomatoes: The gross weight of the whole can, or the net weight of tomatoes only. Both are valid measures of the weight of a can of tomatoes, although the gross weight is always greater. The gross and net weight, like GO and VA, are not independent estimates. They can be calculated using the same method and assumptions (a scale) and the same data (same can of tomatoes). Instead they are estimates of different concepts.

Like GO and VA, the net and gross weight of tomatoes are appropriately used in different contexts. One cannot cook a recipe based on the gross weight of the can of tomatoes. One also cannot go to the post office and demand to ship a can paying only for the net weight. If a regulator were to force the post office to ship cans based on the net weight, then the post office would be systematically undercompensated due to the regulator using the wrong measure. Finally, it would not serve any purpose to try to average or otherwise combine the net and gross weights as the resulting number would be meaningless.

Only GO estimates result in a consistent and unbiased approach for ED2

Our estimates of historical TFP growth will inform an OE assumption. We must therefore use an estimate calculated against the same cost base, that is the same set of inputs, as the cost base to which the OE assumption will apply. There are therefore two approaches to ensuring that the cost base of the estimate is consistent with the cost base for the assumption:

- **GO approach**: The OE assumption is applied to **all costs**, regardless of whether they are capital, labour, or intermediate inputs. In this case a **GO** measure is appropriate; or
- **VA approach**: The OE assumption is only applied to **primary costs**, i.e. only to capital and labour, but not intermediate inputs. In this case a **VA** measure is appropriate.

There is therefore not an isolated choice between GO and VA measures, but a choice between two separate, internally consistent ways of setting an OE target. It is an inconsistency and an error to calculate an OE estimate using one cost base, and then to apply the estimate as a requirement on a different cost base.[82] This error will result in a biased requirement:

- Applying a (lower) GO estimate, calculated against gross inputs, to a (smaller) cost base of only capital and labour results in a total requirement that is biased downwards, i.e. less ambitious than what the estimates support; conversely,

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82 Section 3.4.1 explains how regulators, including Ofgem, have misunderstood the choice between GO and VA measures in past decision.

- Applying a (higher) VA estimate, calculated against primary inputs of only capital and labour, to a (larger) cost base including gross costs results in a total requirement that is biased upwards, i.e. more ambitious than what the estimates support.

The OE requirement for RIIO-ED2 will be applied to totex, which is a measure of gross costs. It includes the costs of capital, labour, and intermediate inputs. Since totex is a gross cost measure of inputs, it is necessary to use a consistent gross approach when estimating historical OE. This means using GO estimates of TFP growth from EU KLEMS.

While the RIIO framework applies the OE assumption as a reduction in allowed costs, it is also the case that the GO framework is consistent with the treatment of outputs (or drivers) under RIIO, while the VA framework and VA estimates are not. The drivers that Ofgem has used for cost assessment for past RIIO decisions are gross outputs in the sense that they are measures of services provided that are not in any way reduced to reflect DNOs' use of intermediate inputs.[83] As such the RIIO framework uses both gross outputs and gross costs, and therefore should set an OE requirement based on GO estimates as part of a consistent GO approach.

3.1.4. Summary of past UK regulatory approaches

Several UK regulators have used estimates from growth accounting approaches to set assumptions on OE. Regulators have taken different approaches to using growth accounting estimates, as summarised in Table 3.1.

83 It is not clear what it would mean to have a value-added measure of outputs for DNOs given that several drivers, such as customer numbers and network length, are not expressed in monetary terms. A consistent VA approach would therefore need to develop a method for subtracting monetary intermediate inputs from the non-monetary outputs to derive a measure of the value added, either in monetary or non-monetary terms.

Table 3.1: Summary of Relevant Regulatory Decisions

	RIIO-T1/GD1	RP5 Appeal	PR19 FD	PR19 Appeal	RIIO-T2/GD2
Date of Decision	December 2012	March 2014	December 2019	March 2021	December 2020
Regulator	Ofgem	CC	Ofwat	CMA	Ofgem
Companies Regulated	T and GD in GB	ET & ED in NI	Water in E&W	Water in E&W	T and GD in GB
Data Window	1970 to 2007	1970 to 2007	1999-2007 – pre-crisis 2010-2014 – post-crisis	1999-2007 – pre-crisis 2010-2014 – post-crisis	1997 to 2016
GO vs VA	Both	Both	GO, with regard to VA	GO, with regard to VA	VA
Comparator Sectors	Both	Wide	Narrow	Narrow	Wide
Approach to Available Range	Capex OE is taken from top-end of Construction TFP index. Opex OE is taken from within a range of 0.5-2.8% p.a.	Midpoint of lower bound (0.5%) and upper bound (1.5%)	Ofwat takes from near the top of Europe Economics' range to account for (a) VA measures; and (b) totex/outcomes benefits.	CMA used the average of the estimated range (0.7%), adjusted upwards to reflect qualitative factors	Top of estimated historical range, plus 0.20 percentage points to reflect innovation, plus an additional unexplained 0.05 percentage points.
Final Ongoing Efficiency Assumption	Capex: 0.7% Opex: 1.0%	1.0%	1.1%	1.0%	Capex: 1.15% Opex: 1.25%

Notes: At the time of writing Ofgem's RIIO-T2/GD2 Final Determinations for all networks are under appeal. The table does not include a summary for RIIO-ED1 as Ofgem's Final Determinations accepted the assumptions in DNOs' business plans rather than calculate a common OE requirement, as Section 2.3.1 discusses.

The decisions use different approaches and different estimates across the key methodology decisions outlined in this section:

- Some decisions (PR19) use narrow comparator sets, others use wide comparator sets (RP5 and RIIO-T2/GD2), and one uses both (RIIO-T1/GD1);
- Some decisions (RIIO-T1/GD1 and RP5) use longer and older data series, others use shorter and more recent data series (PR19 and RIIO-T2/GD2);
- Some decisions (PR19) primarily used GO estimates, others use a mix of GO and VA (RIIO-T1/GD1 and RP5), and one primarily uses VA (RIIO-T2/GD2); and
- The decisions use different approaches for picking a single assumption from the range of estimates, or in the case of Ofgem's RIIO-T2/GD2 Final Determinations, from outside the range of estimates.

Given the variation in approaches, regulatory precedent provides few prescriptions for selecting samples and estimates. Section 3.2 therefore explains each methodology decision in terms of economic best practice. Section 3.4 reviews and draws lessons from selected errors and misconceptions in the most recent energy networks decision, namely Ofgem's Final Determinations for RIIO-T2/GD2.

3.2. TFP Estimates based on EU KLEMS

3.2.1. Introduction to the EU KLEMS database

EU KLEMS is a pan-European database that contains industry-level measures of outputs, inputs, and productivity for the EU28, plus the US and Japan, for the period from 1970 onwards.[84] These measures include the input categories of capital (K), labour (L), energy (E), materials (M), and services (S). Energy, materials, and services (EMS) together constitute intermediate inputs (X).

EU KLEMS publishes two datasets:

- The NACE 1.1 dataset – which contains productivity data where output is measured on the basis of both gross output (GO) and value added (VA). The data series covers the period from 1970 to 2007; and[85]
- The NACE 2 dataset– which contains productivity measures based on VA output measures only and follows a different sector classification from NACE 1.1. The data series runs from 1997 to 2017.[86]

3.2.2. EU KLEMS estimates have several known problems

Theoretical assumptions

The growth accounting framework rests on several assumptions about the real economy. It assumes that factor input markets are competitive. If this assumption holds then the price paid for each input reflects its productive value, and weighting inputs by expenditure shares results in an accurate index of inputs. The weights on the inputs (as set out in equation (3) in Section 3.1.1) therefore assign inputs which have a higher price a larger influence over the combined input index. For example, an additional hour worked by a high-skilled worker counts as a greater increase in the labour services input than an hour worked by a low-skilled

[84] O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538 pp. F374-F403.

[85] NACE stands for the *Nomenclature générale des activités économiques dans les Communautés Européennes*, and is the obligatory statistical classification introduced by the EU in 1990.
ONS (1997) Annual Abstract of Statistics, p. 1.

[86] NACE 2 is based on a revised industry classification. The EU KLEMS website notes that: "*The National Accounts (NA) data in the new classification is typically provided for shorter time series than were previously available in the NACE 1 classification. We back-cast time series of output and labour data using growth rates from the earlier data in the NACE 1 classification. These imputations are denoted in grey in the new release.*"
URL: http://www.euklems.net/eukNACE2.shtml

worker, due to the former's higher wage rate. The EU KLEMS database assumes that this higher wage reflects a higher level of inputs per hour worked.[87]

The growth accounting framework also assumes that there are constant returns to scale (CRS). The weights placed on the components of output, e.g. labour compensation as a proportion of nominal output, are intended to approximate production elasticities (i.e. the percentage effect on outputs of a 1 per cent change in individual inputs).[88] If the assumption of CRS does not hold, then the TFP measure will reflect the effect of scale economies as well as productivity growth.

Estimates from EU KLEMS are based on the productivity of the whole sector, not selected frontier firms. They do not distinguish between increased TFP from ongoing efficiency and from catch-up improvements. If there is systematic catch-up (or divergence) in efficiency across the sample period, then this will add to estimated productivity growth. Systematic convergence or divergence is less likely to occur over long time periods. If it did, firms would eventually either all catch-up to the efficient frontier, or some firms would be too far from the efficient frontier to remain viable in competitive industries.[89]

The framework also assumes that there is full utilisation of inputs, and that all companies are technically efficient.[90]

Data measurement errors

The guidance notes on the methodology and the construction of the KLEMS database highlight a number of health warnings with the data.[91]

Data collection

In general, the data is likely to be less reliable for more narrowly defined industries as more detailed industry specifications tend to draw on a wider range of data sources (which may not

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[87] For example, if the weightings reflect marginal cost, and the factor market is competitive (such that the worker's compensation equals his/her output value), then a change in the composition of labour does not affect TFP. However, if these conditions do not hold, the residual TFP measure will pick up any deviations from the assumption that marginal costs equal marginal revenues (in both labour and other factor markets). For example, in the case of imperfect competition, an increase in pricing above marginal cost will be picked up by a decline in the residual TFP measure.
O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538, pp. F374-F403.

[88] OECD (2001), "Measuring Productivity, Measurement of aggregate and industry level productivity growth", *OECD manual*, p. 18.

[89] The CMA recognised this argument in their Provisional Findings for PR19.
CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.365.

[90] This assumption is not as strong as one might expect. Technical efficiency can include some apparent "inefficiency" in production, if the management cost of eliminating the problem would exceed the value of the increase in output or the reduction in inputs. Thus "technical efficiency" may not require the elimination of all "X-inefficiency" in the management of a firm. Technical efficiency means only that the owners and managers of the firm ("principals") are managing their employees ("agents") and other inputs so as to maximise the firm's profits.

[91] O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538.
OECD (2001) "Measuring Productivity, Measurement of aggregate and industry level productivity growth", *OECD manual*, pp. 21-24.

be consistent or complete). The database's authors also acknowledge that data from further back in the time series has a greater likelihood of measurement error.[92]

Output data

Measuring output volumes over long periods necessitates identifying and adjusting for changes in quality, generally by constructing a quality-adjusted price deflator. Measuring and valuing quality changes "is one of the most difficult problems in price and volume measurement".[93] If KLEMS does not fully take account of improvements to output quality, then estimates will understate productivity improvements.

Adjusting for quality can be particularly difficult in the services sector, e.g. for financial and business services. The impact of mismeasurement can also be especially large for high-technology industries where there are rapid quality changes, such as changes in the power of computers.[94] However, the problems are prevalent in a number of sectors. For example, utility sectors have achieved substantial improvements in quality of service since privatisation.

Input data

In relation to input measures, as we have noted above, the KLEMS database distinguishes labour inputs for 18 different categories. These categories do not accurately measure the quality of labour input. For example, KLEMS only distinguishes between three levels of educational attainment. To distinguish between these categories, KLEMS relies on labour force survey data, where there are issues over the consistency of measuring labour inputs over time.[95]

EU KLEMS measures capital inputs as a flow of services, rather than capital expenditure. This requires an estimate of stock of capital, which is not directly observed. KLEMS therefore has to construct a measure of the capital stock based on investment data and assumed capital depreciation. Any inaccuracies in the EU KLEMS assumptions on depreciation introduces measurement error in the constructed capital stock, and by extension capital services.[96]

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92 The authors state: "*As a general rule the reliability of the data is likely to be lower [...] the more we more from the industry level identified in the National Accounts. This is because to break down the national accounts series, we often had to rely on additional data sources* […]."
O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538, p. F390.

93 Eurostat (2016), Handbook on process and volume measures in national accounts, p. 20.

94 OECD (2001) "Measuring Productivity, Measurement of aggregate and industry level productivity growth", *OECD manual*, pp. 21-24.

95 O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538, p. F380.

96 The authors also note that one of the more stringent assumptions in capital services measurement is the assumption of constant returns to scale as capital services are constructed employing user costs of capital as weights assuming an ex post rate of return. It is assumed that the total value of capital services for each industry equals its compensation for all assets. This approach yields an internal rate of return that exhausts capital income and is consistent with returns to scale.
O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538, p. F394 and Appendix B.

The measurement of capital inputs is also sensitive to the assumption of full utilisation. The variable use of capital inputs, i.e. the measurement of machine hours, is rarely used in the construction of the KLEMS database. Instead, KLEMS records the fixed capital stock. Consequently, a higher rate of capacity utilisation in periods of expansion is accompanied by output measures that show rapid growth whilst input measures remain stable, thus producing a rise in measured TFP. The converse holds for periods of recession. In such conditions, only long-term measures of TFP provide any indication of the underlying trends.

Implications

The estimates of historical TFP growth in EU KLEMS suffer from several sources of error. The data itself contains measurement error, struggles to capture changes in the quality of both inputs and outputs, and relies on several modelling assumptions to construct a measure of capital. Its approach to calculating productivity measures requires a set of assumptions about the real economy that are inaccurate, and in some cases systematically false.

The problems of the database do not mean that it is inappropriate to rely on EU KLEMS estimates. The database is a source of relevant long-term data, and other measures and approaches have their own imperfections. However, estimates should be used with caution given the uncertainty embedded in them. This has two practical implications.

First, only limited weight can be placed on individual estimates. Estimates that result in extreme results, either high or low, are more likely to be driven at least in part by errors.[97] Likewise, estimates for narrowly defined comparator sectors or short sample periods are more likely to be biased in one direction by individual sources of error than estimates for broadly defined sectors or long sample periods. We therefore avoid placing undue weight on extreme or narrow estimates.

Second, estimates from KLEMS should be used alongside estimates from other sources. Estimates from other sources have different advantages and disadvantages from EU KLEMS. They are therefore less likely to embed the same errors and biases as EU KLEMS estimates. This report therefore uses results from other approaches alongside KLEMS. These should be treated as independent estimates rather than applying subjective or qualitative adjustments.

3.2.3. GO is the measure of OE relevant to a requirement on totex

EU KLEMS contains estimates for both GO and VA TFP growth. As Section 3.1.3 explains, the two measures differ in their treatment of intermediate inputs. GO measures include intermediate inputs in the cost base against which TFP is calculated. VA measures exclude intermediate inputs both from the measure of output and from the measure of inputs. Because it measures growth against the narrower cost base, estimates of VA growth are always higher (in absolute terms) than estimates of GO growth.

3.2.4. Choice of sample period

While trends in productivity are long-term in nature, they can be volatile over shorter time periods. Estimates of productivity growth over shorter time periods are also more likely to contain the impact of catch-up improvements than longer term estimates, as we describe in Section 3.2.2. Productivity estimates should therefore use the longest sample period possible.

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97 We use “extreme” in the mathematical sense that the estimate is towards either end of the range of estimates.

When using GO estimates, available from the NACE 1.1 dataset, the longest available sample period is 1970-2007. Our sample period is therefore 1970 to 2007.

Trends in productivity are also cyclical. Productivity growth is typically higher during the recovery phase of a business cycle, and lower or negative during recessions. There are two common approaches to limiting the impact of cyclicality on estimates of productivity trends:

- Using a long sample period that spans several business cycles. This limits the influence of any one cycle on estimates. This section follows this approach.
- Limiting the sample periods to include only full business cycles. Some regulators, including Ofgem, have previously used this approach.[98] This section does not use this approach.

There are two reasons why limiting the sample to full business cycles does not meet the criteria for a high-quality approach set out in Section 2.1:

First, identifying business cycles introduces subjectivity to the choice of sample periods. There is no consensus on the precise dating of peaks and troughs, and small changes to the sample period can affect trend estimates.[99] Making decisions on the start and ends of the sample period, instead of taking the longest period available, requires judgements that introduce uncertainty and scope for cherry-picking.

As an example, consider two recent attempts by regulators to implement the full business cycle approach:

- In its Provisional Findings for PR19, the CMA identified 1980 to 1989 and 1990 to 2007 as "the two most recent full business cycles". It also identified the post-Great Recession period as starting in 2010.[100]
- In its RIIO-T2/GD2 Final Determinations Ofgem relied on estimates from consultant CEPA, which used a full business cycle approach. CEPA identified the recent UK business cycles over the same period as 1978 to 1986, 1986 to 1997, 1997 to 2006, and 2006 to 2016.[101]

Collectively, the CMA and Ofgem/CEPA have identified a total of thirteen years as start or end dates for UK business cycles but have not agreed in a single case. They also disagree on the number of business cycles as Ofgem/CEPA consider that a business cycle ended in the late 1990s, while the CMA believes there was a single business cycle from 1990 to 2007. Ofgem/CEPA consider that the post-Great Recession period constituted a complete cycle by

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98 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.25.
CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p. 17.

99 In its report for Ofgem ahead of RIIO-T2/GD2, CEPA notes that changing the start of the sample period by two years would double its estimate of TFP growth for some sectors.
CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 37.

100 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.305.

101 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, pp. 18-19.

2016, the CMA does not. This illustrates the subjectivity and uncertainty that is inherent in attempting to pinpoint business cycles, which our approach avoids.

Second, reducing the sample period to exclude incomplete cycles exacerbates other sources of error. A longer period mitigates problems with measurement error and separating ongoing efficiencies from catch-up improvements, as Section 3.2.2 describes. It also better identifies longer-term trends in productivity. Dropping observations therefore reduces the precision of estimates.

3.2.5. Choice of comparator sectors

This report uses a wide definition of comparator sectors as the starting point for KLEMS estimates. A wide comparator group reduces the reliance on estimates for individual sectors and the impact of measurement errors, as we explain in Section 3.2.2. It also eliminates the subjectivity in selecting individual comparator sectors and reduces the scope for cherry-picking. This section therefore uses EU KLEMS estimate for TFP growth for all UK market sectors, both as an unweighted average and as an average weighted by share of total market sector output.[102]

It also considers three sets of comparator sectors selected on the grounds that their activities more closely resemble electricity distribution. The comparator sectors reflect the comparators in three relevant regulatory determinations:

- The set of comparators that Ofgem used for DPCR5, as well as for RIIO-ET1;
- The set of comparators recommended by CEPA for RIIO-T2/GD2; and[103]
- The set of comparators that the ACM used in its recent TSO method decision, which Section 2.4.2 describes.

Table 3.2 shows which comparator sectors are included in each set, and the arithmetic average of the GO TFP growth rate for each sector. Table 3.2 also illustrates the pitfalls of relying on narrow comparator sets, both because different decisions have settled on different sets of comparators and because the TFP growth estimates range from *minus* 0.4 per cent to *plus* 1.6 per cent per year. Subjective decisions on comparator sectors will therefore results in different estimates, which creates scope for a selective reading of the evidence.

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102 We do not include non-market sectors. Productivity estimates for non-market sectors (including electricity distribution) suffer from the problem that their outputs cannot be measured and valued at market prices. Specifically, we exclude the NACE 1.1 sectors real estate, public administration, education, health and social work and community services.
See O' Mahony, M. and Timmer, M.P. (2009), "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS database". *The Economic Journal*, vol. 199, Issue 538, p. F394.

103 The "selected industries (exc. manufacturing)" that CEPA included in its "reference value". Ofgem implicitly did not rely on this comparator sector by picking the upper bound of CEPA's range of reference values.
CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 13.

Table 3.2: Comparator Sectors used in Relevant Regulatory Decisions

Sector	NACE 1.1 Code	DPCR5	T2/GD2	ACM	TFP GO Growth p.a. 1970-2007
Manufacture of chemicals and chemical products	24	Y	N	N	1.3%
Manufacture of machinery and equipment n.e.c.	DK	N	N	Y	0.5%
Manufacture of electrical and optical equipment	DL	Y	N	N	1.6%
Manufacture of transport equipment	DM	Y	N	N	1.0%
Electricity, gas and water supply	E	N	N	Y	0.8%
Construction	F	Y	Y	Y	0.2%
Sale, maintenance and repair of motor vehicles; Retail sale of fuel	50	Y	Y	N	1.0%
Transport and storage	60t63	Y	Y	Y	1.2%
Post and Telecommunications	64	N	N	Y	1.6%
Financial intermediation	J	Y	Y	Y	-0.4%
Business services	71t74	N	N	Y	-0.1%

Notes: Ecorys and CEPA used NACE 2 rather than the NACE 1.1 sector classifications used in this report. We have used the closest equivalent NACE 1.1 category identified using correspondence tables. Business services covers both the categories of "Professional, scientific, technical, administrative and support service activities" and "IT and other information Services" as used by Ecorys, which correspond to NACE 1.1 coded 72 and 74 respectively.
Source: Ofgem, CEPA, Ecorys, and Eurostat.[104]

3.2.6. EU KLEMS estimates indicate historical ongoing efficiency of 0.5 per cent

Table 3.3 shows the average growth rate for each of the comparator sets. The averages for the DPCR5 and RIIO-T2/GD2 comparator sets, and one whole economy measure, are unweighted. The other whole economy measure weights each sector by its share of output. Each sector in the ACM comparator set receives the weight that the ACM assigned to it based on the Ecorys study.[105]

[104] Ofgem (8 May 2009(, Electricity Distribution Price Control Review: Methodology and Initial Results Paper, p. 86.
CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, Table 2.1.
Ecorys (15 January 2019), Wegingsfactoren voor frontier shift TSO's, Table 1.1.
Eurostat (23 July 2008), Correspondence table NACE Rev. 2 - NACE Rev. 1.1.

[105] Average weight across GTS and TenneT.
Ecorys (15 January 2019), Wegingsfactoren voor frontier shift TSO's, Table 1.1.

Table 3.3: Average GO TFP Growth 1970-2007 by Comparator Set

Comparator Set	Weighting	Average TFP GO Growth 1970-2007
Whole economy (excluding non-market sectors)	Unweighted	0.4%
Whole Economy (excluding non-market sectors)	Weighted	0.3%
DPCR5	Unweighted	0.8%
T2/GD2	Unweighted	0.5%
ACM	Weighted	0.5%
Mean and Median		**0.5%**

Notes: Arithmetic means.
Source: NERA analysis of EU KLEMS data.

The EU KLEMS estimates indicate that historical OE in comparator sectors has been 0.5 per cent. The mean annual growth in GO TFP across the five EU KLEMS estimates is 0.5 per cent, as shown in Table 3.3. 0.5 per cent is also the median of the sample, which has a range of 0.3 to 0.8 per cent. The upper bound is driven by the high-growth manufacturing sectors included in the DPCR5 comparator set, while the whole-economy measures are below the average.

3.3. UK Sources of Productivity Estimates

This section also surveys data from other UK and international institutions that that have analysed historical productivity for the UK economy using growth accounting approaches. These estimates provide a cross-check on the EU KLEMS estimates. The estimates are also complementary to the KLEMS evidence as they cover a more recent sample period than the NACE 1.1 data set. Several of the institutions also forecast UK productivity growth, as Section 5.2 discusses in more detail.

The estimates published by the institutions surveyed in this section are VA estimates. As such they cannot be directly used to inform an OE target for a cost base that includes intermediate inputs, such as totex, as Section 3.1.3 explains. VA measures are always higher than GO estimates and applying the VA estimates as an OE requirement would introduce bias. VA estimates therefore need to be adjusted to take account of the share of intermediate inputs in GO to be comparable with GO measures.[106]

3.3.1. ONS estimates for all market sectors

The UK's Office for National Statistics (ONS) publishes estimates of UK multi-factor productivity (MFP) based on a growth accounting approach.[107] The data covers all market sectors and 19 component sectors and is available as annual estimates from 1994 to 2019.

106 Specifically, we multiply the VA estimate by the share capital and labour inputs in GO for all sectors. This share is 46.6 per cent on average across 1970 to 2007, using the NACE 1.1 EU KLEMS data. Section 3.1.3 explains this relationship in more detail.

107 The ONS does not consider MFP a national statistic, but instead classifies it as an experimental statistic. ONS Website (13 March 2020), Multi-factor productivity (MFP) QMI. URL:

The ONS estimates average annual growth in VA productivity of 0.66 per cent.[108] Since this is a VA measure it is higher than what the corresponding GO measure. In adjusted GO terms, the annual growth rate estimated by the ONS is approximately 0.31 per cent per year. The ONS estimate is lower than the 0.5 per cent average of the EU KLEMS estimates. It is however consistent with the lower bound of the 0.3-0.8 per cent range of KLEMS estimates.

3.3.2. The Bank of England's analysis in its Monetary Policy Report

The Bank of England publishes estimates of both historical and forecast productivity growth as part of its Monetary Policy Reports. The Bank calculates VA estimates using a growth accounting approach.

In its last Monetary Policy Report prior to Brexit and the COVID-19 pandemic, published in January 2020, the Bank presented estimates for TFP growth for ten years before the Great recession (1998-2007) and ten years after (2010-2019).[109] The Bank's estimates will be biased upwards as estimates of long-term growth given that they do not cover the years at the height of the Great Recession.

The average of the Bank's estimates of historical growth in VA productivity is 1.0 per cent, equivalent to 0.5 per cent GO growth. [110] This is consistent with the mean EU KLEMS estimate of 0.5 per cent. However, the Bank's estimate is most likely high due to the exclusions of the recession years 2008 and 2009 from its analysis. This provides evidence that trend productivity growth has been less than the EU KLEMS estimate of 0.5 per cent, when considering all years from 1998 to 2019.

3.3.3. OBR assumptions on productivity growth

The Office for Budget Responsibility (OBR) forecasts labour productivity growth as part of its Economic and Fiscal Outlooks. Labour productivity forecasts are partial factor productivity measures, as opposed to total factor productivity measures, and are therefore not relevant to an OE requirement on totex. However, the OBR has also separately estimated both historical and forecast TFP growth.[111]

The OBR has estimated average VA productivity growth from 1998 to 2017 of 1.0 per cent p.a., equivalent to 0.5 per cent GO growth.[112] This is consistent with the mean of the EU KLEMS estimates.

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https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/methodologies/multifactorproductivityqmi. Visited on 18 March 2021.

108 Arithmetic average for from 1994 to 2019.
ONS (19 January 2021), Multi-factor productivity estimates, Dataset MFP01, Table A10.

109 Bank of England (January 2020), Monetary Policy Report, Table 4.A.

110 Bank of England (January 2020), Monetary Policy Report, Table 4.A.

111 OBR (13 March 2018), Productivity growth: international comparisons.

112 OBR (13 March 2018), Productivity growth: international comparisons.

3.3.4. OECD statistics for the UK economy

The Organisation for Economic Co-operation and Development (OECD) compiles statistics on economic growth across its members states, including for the UK. This includes year-on-year multi-factor productivity growth from 1985 to 2019.

The OECD estimates average VA productivity growth of 0.8 per cent, equivalent to 0.4 per cent GO growth, from 1985 to 2019.[113] This estimate is lower than the mean EU KLEMS estimate of 0.5 per cent, but within the range of KLEMS estimates.

3.4. Review of Ofgem's Use of Growth Accounting Estimates

This section clarifies important misconceptions about growth accounting estimates, drawing on the example of Ofgem's Final Determinations (FD) for RIIO-T2/GD2 and the advice provided by its consultants, CEPA.[114] It is not a comprehensive review of the errors in Ofgem's decisions. Instead it draws lessons and explains the mistakes in arguments used to support approaches that this report avoids. Section 5 includes a similar review of regulatory arguments for adjustments to the OE assumption separate from the evidence contained in estimates of historical OE.

3.4.1. Ofgem has erroneously applied VA measures to set requirements on totex

The source of error and bias with the highest impact in Ofgem's FD for RIIO-T2/GD2 is that it uses VA estimates of historical OE improvements rather than GO estimates.[115] As Section 3.1.3 explains in detail, RIIO is a framework based on gross outputs and a gross measure of costs (totex). It is therefore consistent with GO estimates of productivity, but not consistent with VA estimates. Since VA estimates are systematically higher, Ofgem and CEPA's reliance on VA measures biases the OE assumption upwards.[116]

Ofgem and CEPA primarily support their use of VA estimates by referring to regulatory precedent rather than advancing arguments that have economic merit.[117] As the decisions surveyed in Section 3.1.4 showed, UK regulators have in the past used both GO and VA

113 OECD (2021), Multifactor productivity (indicator). doi: 10.1787/a40c5025-en, Visited on 19 March 2021.

114 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised).
CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations.

115 While Ofgem's FD claims to have placed at least some weight on GO measures, this appears not to be the case. Ofgem sets a VA target that is higher than the highest VA estimate provided by CEPA. Since GO estimates are always lower than VA estimates (in absolute terms), it is unclear how this could result from a weighted average of VA and GO estimates.
See CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p.24.

116 The difference between CEPA's GO and VA estimates for its preferred economy-wide comparator set is 50 bps for both TFP and labour productivity.
CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p.6.

117 See for example Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (revised), para. 5.22; and CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p.24.

estimates, although no other regulator surveyed has set an OE assumption based solely or primarily on VA estimates.

The main argument that CEPA advances with economic content is that there may be sources of measurement error in GO estimates:[118]

> "One argument made in favour of the GO measure is that by identifying intermediate inputs as a controllable factor of production, it better reflects the business decisions taken by companies. However, producing consistent sets of GO measures across industries requires careful treatment of intra-industry flows of intermediate products, which may be difficult empirically."

There are two problems with this line of reasoning to support the use of a VA estimate. First, it is not clear why this empirical problem would be so important that it should be given decisive weight. Section 3.2.2 surveys the many problems with measurement error and flawed modelling assumptions that affect EU KLEMS estimates, including the VA estimates that CEPA and Ofgem rely on. CEPA cites no sources and provides no evidence to suggest that errors in the measurement of intra-industry flows of intermediate inputs create greater errors in estimates than other measurement errors and assumptions inherent to the EU KLEMS database.

Second, if CEPA and Ofgem somehow believe that these intra-industry flows should be a dominant concern, it is not an appropriate remedy to apply VA estimates as an OE assumption. As Section 3.1.3 explains, there is a higher-level choice between a consistent GO approach and a consistent VA approach to applying an OE requirement. If for whatever reason Ofgem cannot have confidence in GO estimates, then it can choose to instead use an approach that applies a VA-estimated OE assumption to primary costs only.[119] What it cannot do without biasing the requirement upwards is to apply a VA-estimated assumption to the gross-cost measure that is totex.[120]

3.4.2. Ofgem has set requirements based on a selective reading of the evidence

Ofgem used the available growth accounting estimates selectively to arrive at its OE assumption for RIIO-T2/GD2. As Section 3.2.2 explains, the uncertainty embedded in EU KLEMS estimates means that it is inappropriate to place weight on individual estimates, and in particular on more extreme results. Ofgem did not take account of this when setting the OE assumption.

The selective and subjective use of evidence includes the way Ofgem and CEPA distilled the range of KLEMS estimates for different sectors and sample periods into a single OE assumption. For example, CEPA calculated TFP estimates for 10 different combinations of

118 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 11.

119 Such an approach would have its own difficulties, such as identifying the intermediate inputs of companies.

120 In the context of the tomato analogy from Section 3.4.1, what CEPA and Ofgem have done is the equivalent of relying on the gross weight of the tomatoes while following a recipe framework based on the net weight of tomatoes. Their justification is that they think using the net weight requires "careful treatment" of the metal weight of the can. The result is a biased estimate.

comparator sets and sample periods.[121] However, Ofgem appears to have only relied on the second highest of the ten estimates to set the requirement rather than drawing on the whole body of evidence.[122]

Ofgem's subjectivity results in a higher requirement than a balanced reading of the evidence would. The mean annual growth in TFP across the ten estimates CEPA presented is 0.42 per cent and the median growth rate is 0.35 per cent.[123] The estimate for the comparator set that Ofgem based its OE assumption on was 1.0 per cent.[124] Ofgem and CEPA's reliance on a single estimate therefore increased their conclusions on an appropriate target beyond what an assessment of the whole body of evidence presented would support.

3.4.3. Ofgem's inconsistent use of partial and total factor productivity measures has biased requirements at RIIO GD2 and T2

Ofgem's asymmetric use of partial and total factor productivity measures also risks introducing error to its estimated RIIO-T2/GD2 OE assumption. In its FD, Ofgem used a TFP measure to set the target for capex (including repex), but a measure of partial factor productivity - labour productivity - to set the requirement on opex.[125]

Total factor productivity is in effect a weighted combination of the partial factor productivities (PFP) of each of the inputs included in the TFP measure. As such, partial factor productivity growth will be faster than TFP growth for some inputs, and slower for others.

In the FD, Ofgem asymmetrically applies the faster-growing labour partial factor productivity estimates to the cost category it believes to be disproportionately made up of labour costs. It does not however apply the slower-growing partial factor productivity estimates for other inputs (capital) to cost categories that are disproportionately made up of capital inputs.

Ofgem therefore applies PFP measures for categories of costs where PFP growth for the dominant input is higher than TFP growth, but applies TFP measures for categories of costs where TFP growth is higher than PFP growth for the dominant input. This results in a higher OE assumption than either consistently applying a TFP estimate or applying the relevant PFP estimates all cost categories would support. The asymmetry therefore introduces an upwards bias in the total OE requirement.

3.5. Conclusions

This section surveys the evidence from growth accounting approaches on historical OE growth. Both the mean and median estimate from EU KLEMS is 0.5 per cent TFP growth

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121 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 15.

122 Ofgem based its OE assumption on what CEPA identifies as a "more stretching OE challenge", which for both TFP and labour productivity is 0.05 percentage points above the weighted average for its economy-wide comparator set. CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p. 7

123 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 15.

124 In CEPA's updated report ahead of the FD it revised this estimate to 0.9 per cent. CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p. 6.

125 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (revised), para. 5.21.

p.a. Of the estimates for the five comparator sets, two are lower than 0.5 per cent, and one is higher. The evidence from the EU KLEMS database therefore supports an OE assumption of 0.5 per cent.

This section also reviews four growth accounting estimates from institutional sources. All four estimates are within the range of the EU KLEMS estimates. However, three of the four estimates are either lower than 0.5 per cent, or otherwise indicate that 0.5 per cent may be a high estimate. This evidence is therefore broadly consistent with a 0.5 per cent estimate for the trend in OE growth but suggests that the true value may be lower than this.

The section separately considers Ofgem's use of EU KLEMS estimates for RIIO-T2/GD2. Ofgem made several errors and selectively singled-out individual pieces of evidence. This includes incorrectly using VA instead of GO estimates, relying on extreme estimates, and asymmetrically using measures of partial factor productivity. In each case this led to a higher estimate than a correct and balanced reading of the evidence would support.

4. Estimating Historical DNO Productivity Growth

This section presents estimates for the historical ongoing efficiencies achieved by DNOs from 2010/11 to 2019/20. We derive the estimates using an approach based on Törnqvist indices. Section 2.2.2 discusses the conceptual framework and its advantages. This section proceeds as follows:

- Section 4.1 provides an overview of the approach alongside important qualifications on the limitations and appropriate interpretation of the analysis;
- Section 4.2 explains the measure of DNO inputs;
- Section 4.3 sets out criteria for good measures of DNO outputs and details the outputs used in this section's modelling;
- Section 4.4 outlines the cost regression method for selecting model specifications and deriving output weights;
- Section 4.5 presents the five selected model specifications and the output weights in each;
- Section 4.6 shows the results of the Törnqvist analysis; and
- Section 4.7 assesses the applicability of the historical estimates as an OE assumption for RIIO-ED2.

This section describes the Törnqvist approach, explains key modelling steps, and presents and critically assesses results. Appendix A contains a more detailed mathematical and technical description of the modelling steps.

4.1. The Törnqvist Framework

4.1.1. The Törnqvist approach creates a single measure of output

A fundamental challenge in measuring the productivity of energy networks is that the monetary value of their outputs is not directly observable as the outputs are not sold at market prices. Section 2.2 explains this problem in more detail alongside the methods that are used to overcome this difficulty. The Törnqvist approach is one such method that has been used by regulators in jurisdictions such as Germany and Australia, as Section 2.4 explains.

A Törnqvist index is an index constructed from a weighted combination of the growth rates of two or more constituent components. The benefit of the Törnqvist index is that it creates a single measure of output from multiple outputs that are not expressed in commensurable units (such as customer numbers and network length). Dividing the Törnqvist index of outputs by an index of total costs then creates an index of total factor productivity.

This section uses Törnqvist analysis to estimate the annual productivity improvements achieved by DNOs from 2010/11 to 2019/20. At a high level, the modelling framework resembles the approach in the Australian case study that Section 2.4.1 reviews.[126] The analysis consists of three steps:

- Defining input and output variables, as Section 4.2 and Section 4.3 detail;

[126] See AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors.

- Regression modelling to select model specifications with different combinations of outputs and to derive output weights, as Section 4.4 and Section 4.5 explain; and
- Calculating Törnqvist indices and productivity metrics, as presented in Section 4.6.

4.1.2. The objective and interpretation of the Törnqvist analysis

The objective of the Törnqvist analysis is to estimate the average annual improvement in the rate at which DNOs converted inputs into outputs over the period 2010/11 to 2019/20. The results of the analysis should be interpreted as such. Section 4.7 assesses the extent to which the estimated historical improvements are relevant as indicators of the ongoing efficiencies that will be achievable in RIIO-ED2. Section 6 explains how the Törnqvist estimates inform this report's recommendations for an OE assumption for RIIO-ED2.

For the avoidance of doubt, there are several interpretations that could be made of the Törnqvist analysis in this report that would be incorrect and should be avoided. The Törnqvist analysis involves some steps that are similar to those involved in cost assessment and efficiency benchmarking, such as cost regressions. However, the objective of this section's analysis, of estimating the average *annual improvement* in efficiency, is fundamentally different to that of comparative benchmarking, of assessing the relative *level* of efficiency, and is not suited for the latter purpose. For example, it does not fully take account of fixed effects such as regional differences in price and wage levels or special factors relevant to some subset of DNOs. The omission of external factors that are fixed effects for some DNOs does not bias estimates of the trend in DNO productivity. It would only bias any comparison of efficiency across DNOs. The modelling decisions made in this section and the analysis that supports them therefore do not in any way contain lessons or recommendations for a cost assessment methodology.

It would also be inappropriate to place excessive weight on results for individual model specifications or for individual DNOs. A single model is less likely to provide a full and accurate measure of the services provided by a DNO, and more likely be affected by measurement error in individual variables and regression misspecification. Results for individual DNOs may reflect DNO-specific measurement errors and productivity trends not driven by ongoing efficiencies (including but not limited to catch-up). Setting an OE assumption based on the results for a small number of DNOs would also distort their incentives for achieving productivity improvements, which should be avoided.

4.2. Selecting Inputs

The objective of the Törnqvist analysis is to inform an OE assumption for total factor productivity growth. It should therefore be based on a measure of DNOs' total costs. This analysis calculates total costs as the sum of capital costs and operating costs.

4.2.1. We model capital costs as annuitised payments on the MEAV

The analysis uses a capital stock-based rather than capital expenditure (capex) measure of capital costs. Capital expenditure in a given year is not an input in the production of most DNO outputs in that same year. Instead, each network requires an asset base, or capital stock, to provide distribution services. A measure of capital cost calculated from each DNO's asset base therefore better reflects the actual inputs in the network's production process.

Over time, capital expenditure contributes to the size and quality of the asset base. However, an increase in capex in a given year does not create a proportional increase in the asset base or outputs delivered in that year. Productivity estimates based on capex will therefore tend to find reduced productivity in years when there is higher capital expenditure. Movements in capex will then drive changes in estimated productivity that do not reflect underlying operational efficiency if estimates use a capex measure of capital cost. Using an asset-base measure of capital inputs avoids any spurious movements in estimated productivity from volatility in the rate of investment or changes in investment cycles.

We use the Modern Equivalent Asset Value (MEAV) of each network as the measure of its asset base. MEAV is a replacement-cost measure of the value of each asset for all network assets in a DNO's asset register.[127] Applying a unit cost to each of a DNO's assets results in a measure of the value of the assets it uses in its electricity distribution business. The unit cost approach to constructing an asset base value does not contain depreciation. MEAV is therefore a measure of the value of the capital employed by a DNO that is invariant to time effects or assumptions on depreciation patterns. The modelling uses the same unit cost for each asset category across all years and all DNOs, measured in real terms based on RPI 2012/13 prices.[128]

We calculate the annual capital cost for each DNO in each year as the annuitised cost of the MEAV of its network using an annuity rate. An annuity rate is the payment on a principal (in this case the MEAV of the asset base) that is fixed across all years of its repayment term (in this case the assumed asset life). The annuity rate is set such that over the asset lifetime the net present value of the annuitised costs is equal to the MEAV. Using an annuity rate avoids relying on assumptions on the age profile of network assets and provides an estimate of the value or volume of services provided by the installed asset base in each year.

The modelling uses an annuity rate based on two assumptions:

- A real vanilla weighted average cost of capital (WACC) of 3.57 per cent. This is the arithmetic average of the RIIO-ED1 WACC from 2015/16 to 2019/20 as determined for the slow-track DNOs and published in the Price Control Financial Model (PCFM). We use the same WACC for all DNOs and across all years so that the annuitised capital cost is invariant to changes in regulatory determinations and financial conditions; and[129]
- An assumed asset life of 45 years, as Ofgem determined for the last year of RIIO-ED1.[130]

An annuity rate of 4.50 per cent is consistent with a 3.57 per cent WACC and the assumed 45-year asset lifetime. Multiplying this rate with each DNO's MEAV yields the annuitised cost of the capital employed by each network.

127 In the case of non-countable assets it is the cost per unit, for example per km of cable. We source MEAV data from the Cost and Volumes regulatory reporting pack, Table M15. Units costs reflect Ofgem's ED1 expert view.

128 This is the price base used for RIIO-ED1.

129 Ofgem (27 November 2020), RIIO-ED1 Financial Model following the Annual Iteration Process 2020.

130 Ofgem (27 November 2020), RIIO-ED1 Financial Model following the Annual Iteration Process 2020.

4.2.2. Operating costs are based on statutory accounts

The measure of operating costs (opex) should be consistent with the measure of capital costs. As far as possible these should therefore be costs separate from expenditure on the capital assets included in the MEAV. There is no clear distinction between operating costs and other costs within the price control and regulatory reporting frameworks. For RIIO-ED1, companies also assumed different totex capitalisation rates.[131] Regulatory totex, alongside subcategories of regulatory totex, is therefore not suited as a measure of operating costs for the modelling.

We have relied on operating cost data provided by the DNOs from their statutory accounts. The modelling uses operating costs (excluding exceptional items) net of depreciation and amortisation. We also subtract pass-through costs to exclude cost items not covered within totex.[132]

We convert nominal statutory opex to a real 2012/13 basis using factor price indices and notional cost structures as Ofgem determined for RIIO-ED1.[133] Appendix A.1 describes the construction of a combined factor price index for opex from the RIIO-ED1 determinations. We deflate the nominal statutory opex by the combined factor price index to calculate real opex in 2012/13 prices. This prevents inflation and real price effects from affecting the productivity estimates.

4.3. Selecting Outputs

The second part of observing productivity is to measure the output produced by each DNO. The measure of output should capture the volume and quality of the distribution services the DNO provides to its customers. To do so, a measure of DNOs' outputs should satisfy the following five criteria:

- The output is a measure of or proxy for the services delivered to customers;
- The output drives costs;
- It is possible to estimate a cost weight for the output;
- It is possible to combine the output with other outputs that meet these criteria; and
- Consistent data for the output is available as a sufficiently long time series.

A common pitfall in meeting the first criterion is confusing measures of network outputs and inputs. Both can be proxies for the scale of a network. However, to identify productivity the output variables should reflect the value of the services provided to customers. It should not

131 Ofgem (28 November 2014), RIIO-ED1: Final determinations for the slow track electricity distribution companies: Overview, Appendices 2-6.

132 Total gross pass-through costs as defined in Table C 22 of the Cost and Volumes Regulatory Reporting Pack. The modelling does not deduct pass-through costs associated with SSEH's operation in Shetland as the regulatory reporting framework for these costs changed in the transition from DPCR5 to RIIO-ED1.

133 Ofgem (28 November), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment – Final Decision, Section 12,
Ofgem published data on some cost splits in its Draft Determinations, but not in its Final Determinations. Where relevant we have therefore also drawn on the Draft Determinations.
Ofgem (30 July 2014), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment - Supplementary annex to RIIO-ED1 overview paper, Section 12.

be a variable that is properly considered a network input rather than a measure of the services provided. MEAV is an example of a variable that has been used as a cost driver but is instead a measure of the capital employed by a DNO. It is therefore not suited as an output in the productivity analysis.[134]

The final three criteria are practical conditions that should be met for empirical analysis to be accurate. Variables that in theory would be good measures of the services provided by DNOs can be difficult to implement in practice. This could be because the data availability or quality is inadequate, or that the variables perform poorly in the regression models. For example, where there is a degree of collinearity between outputs, outputs that are strong candidates separately can be unsuited for inclusion in the same regression model. In this case it will not be possible to establish accurate weights for the full set of variables, thereby not meeting the fourth criterion.

Based on the criteria we have identified seven candidate output variables. Four of these could be called scale variables as they are proxies for the volume of services provided by each DNO. Each of the scale variables has been used in regulatory contexts in Great Britain or internationally. They are part of the drivers compiled in the Cost and Volumes regulatory reporting pack that companies submit to Ofgem annually and which is available for all DNOs. The four scale variables are:

- Number of customers;
- Total network length (km);
- Network-wide peak demand (MW); and
- Energy delivered (GWh).

Two of the output variables reflect the quality of service. They are measures of the interruptions to service experienced by customers. As with the scale variables, the quality variables are drivers in the Cost and Volumes regulatory reporting pack. They are:

- Customers interrupted, excluding exceptional events (CI); and
- Customer minutes lost, excluding exceptional events (CML).

We also include an output variable representing distributed generation (DG). Distributed generation is an increasingly large service area for DNOs. Growth in connected embedded capacity may therefore constitute part of the growth in the services provided by DNOs from 2010/11 to 2019/20. The modelling includes the installed capacity (MW) of DG as reported in each DNO's Embedded Capacity Register as a seventh output variable. The data available from the Embedded Capacity Register of two DNOs was not sufficiently complete for all years of the sample period to be used for the modelling. The model specifications that include DG therefore use data for 12 DNOs only.

4.4. Approach to Weighting Outputs

The purpose of using a Törnqvist index is to create a combined index of output from output variables that are not expressed in commensurable units (such as customer numbers and

[134] The scope of this report and the Törnqvist analysis is strictly limited to ongoing efficiency. We are not here commenting on the suitability of using MEAV for cost assessment or other purposes.

network length). The Törnqvist output index is a chained index. Starting from an arbitrary value (such as 1 or 100) in a base year it is calculated such that the growth from one year to the next is a weighted average of the growth of the constituent outputs:

$$\frac{Output_t}{Output_{t-1}} = \left(\frac{Output1_t}{Output1_{t-1}}\right)^{Weigh\ ,Outpu\quad t} \times \left(\frac{Output2_t}{Output2_{t-1}}\right)^{Weigh\ ,Outpu\quad t} \times \dots$$

There are therefore two requirements for calculating the Törnqvist output index beyond having data on each individual output variable. First, it is deciding on the combination of output variables used to construct each Törnqvist index. Second, it is calculating the weights for each output.

Our modelling uses cost regressions to select combinations of output variables and the weight assigned to each variable that is part of the combinations. The modelling regresses sets of output variables on total cost, measured as the sum of capital and operating costs as defined in Section 4.2. All regressions use variables specified as logarithms. The coefficient on each output variable can be interpreted as the percentage change in total costs driven by a 1 per cent increase in the output variable. All regressions also include a constant.

It is not feasible to include all seven output variables in a single regression model. There is a degree of collinearity between the output variables and the sample is 140 observations. A single regression may therefore not have the statistical power to precisely identify the relationship between costs and outputs when required to estimate too many coefficients. A model with all variables can therefore result in coefficients that are estimated with error and that are not statistically significant.

The modelling therefore uses five different model specifications, i.e. five different combinations of output variables. Using multiple model specifications allows the analysis to rely on a range of output variables while avoiding the econometric problems of estimating too many coefficients in one regression. It also minimises the impact of errors or inaccuracies in any one of the model specifications. We select five specifications based on three statistical criteria:

- Each coefficient in the regression should have the appropriate sign, such that delivering higher levels of output drives higher costs. In the case of CI and CML, this means coefficients should be negative;
- The coefficient estimates should be statistically significant; and[135]
- The five models should together cover a variety of output variables.

The regression modelling also provides the output weights within each model specification. Multiplying each coefficient with the corresponding output variable provides a measure of that output variable's impact on modelled cost. The modelling assigns each output variable a weight proportional to its impact on modelled costs. The output weights are averaged across all DNOs but vary across time as is consistent with the methodology for constructing Törnqvist indices.

135 Two of the model specifications contain a coefficient that is not statistically significant at the 5 per cent level. Appendix A discusses the regression results in greater detail.

4.5. Model Specifications

The regression analysis identifies five model specifications based on the criteria set out in Section 4.4:

- **Model 1:** Customer numbers and network length;
- **Model 2:** Peak demand and distributed generation;
- **Model 3:** Customer numbers and distributed generation;
- **Model 4:** Network length and customers interrupted; and
- **Model 5:** Customer numbers, customers interrupted, plus a dummy variable for each DNO.[136]

Appendix A.2 contains the full regression tables for each model specification. Model specifications containing energy delivered and customer minutes lost performed poorly against the statistical criteria. These variables are therefore not included in the five selected model specifications.

The five model specifications cover a range of outputs between them. Model 1 includes two scale variables. Model 2 and Model 3 combine one scale variable with DG to capture the expansion in embedded capacity over the sample period. Model 4 and Model 5 include one scale variable each alongside CI, thereby covering improvements in the quality of service.

The coefficients from the regression modelling determine the weighting of each output variable as Section 4.4 describes. In each model most of the weight attaches to scale variables, as shown in Table 4.1.

Table 4.1: Output Weights across the Five Model Specifications

Weight on Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Customer Numbers	54.2%		97.5%		91.7%
Network Length	45.8%			93.1%	
Peak Demand		86.2%			
Distributed Generation		13.8%	2.5%		
Customers Interrupted				6.9%	8.3%

Source: NERA analysis of DNO data.

4.6. Modelling Results

The Törnqvist estimates of average DNO productivity growth from 2010/11 to 2019/20 range from **-0.1 to +0.4 per cent** p.a. across the five model specifications, as shown in Table 4.2. The average rate of TFP growth across all models is **0.15 per cent**.

136 The DNO dummy variable included in Model 5 captures DNO-specific fixed effects. Variation across DNOs will therefore have less of a role on determining output weights than in other models. To avoid perfect multicollinearity with the constant term there is one dummy variable for each of 13 DNOs. Including DNO dummies controls for variation that is better explained as unmodelled company-specific fixed effects rather than by the output variables. However, because this model specification includes a larger number of variables (two outputs, 13 DNO dummies, and one constant term) it performs worse on statistical significance than the other models.

Table 4.2: TFP Growth Rates in each Törnqvist Model Specification

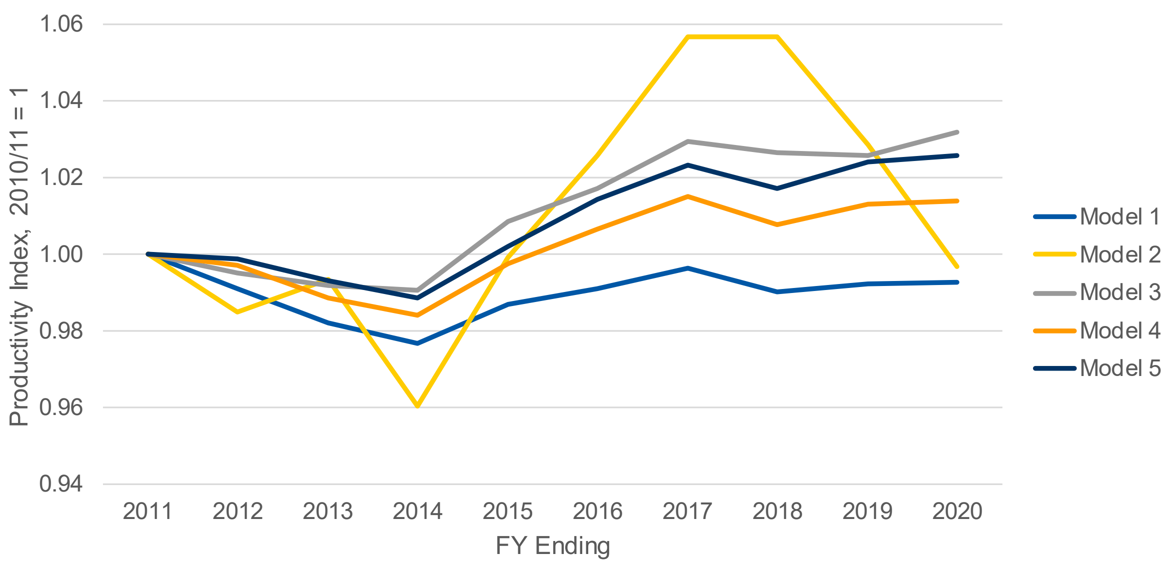
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Average
Customer Numbers	Y		Y		Y	
Network Length	Y			Y		
Peak Demand		Y				
Distributed Generation		Y	Y			
Customers Interrupted				Y	Y	
DNO Dummies					Y	
Average TFP Growth	**-0.07%**	**0.03%**	**0.36%**	**0.16%**	**0.29%**	**0.15%**

Notes: Unweighted arithmetic mean of year-on-year growth rates.
Source: NERA analysis of DNO data.

Including quality and DG outputs in the models increases estimated productivity growth. Model 1, which contains only scale variables, results in the lowest estimate of -0.07 per cent. The estimated rates of growth are higher in the model specifications that include embedded capacity or customer interruptions. This indicates that part of the productivity growth across the sample period has come through DNOs delivering more services to distributed generators and delivering more reliable distribution services. Models that only contain "conventional" outputs, such as the scale variables in Model 1, could then fail to capture some of the productivity improvements achieved by DNOs.

Figure 4.1 shows the evolution of the industry-average productivity index in each model from 2010/11 to 2019/20. The observed productivity trends are similar across four of the models, with lower growth in Model 1 which only contains scale variables than in Models 3 through 5 which also include quality and DG measure. The productivity estimates from Model 2 are more volatile. This reflects the greater volatility of the included scale variable (peak demand) and that Model 2 places greater weight the fast-growing DG variable than the other models.

Figure 4.1: Industry Average Productivity Index, 2010/11 to 2019/20



Notes: Unweighted arithmetic mean of the Törnqvist productivity indices calculated for each DNO.
Source: NERA analysis of DNO data.

The Törnqvist estimates are broadly consistent with the other evidence surveyed in this report. The range of Törnqvist estimates (-0.1 to +0.4 per cent) overlaps with, but is lower than the range of long-term GAA estimates from EU KLEMS (0.3 to 0.8 per cent) and from institutional sources (0.3 to 0.5 per cent) that Section 3 presents. However, the Törnqvist estimates match the GAA estimates for the years after 2010 (0.1 to 0.3 per cent) and the available forecasts (0.0 to 0.3 per cent) that Section 5 reviews. This indicates that DNOs have achieved the same rate of productivity growth as the broader economy since 2010, although this rate has declined compared to the productivity growth observed in the broader economy in the decades prior to 2010.

4.7. Applicability to RIIO-ED2

The Törnqvist estimates in this section represent the form of evidence that is most relevant for the OE assumption for RIIO-ED2. They are based on the productivity growth achieved by DNOs rather than by comparator sectors. This avoids errors from using comparator sectors whose trends may be different from those in electricity distribution.

The Törnqvist estimates are also the most relevant form of evidence in that they are based on the most recent sample period. They capture current productivity trends by using the ten most recent years of data. This avoids error from using data from older sample periods which may not have the same trends as those relevant today, for example due to the productivity slowdown since the Global Financial Crisis of 2007-08. Section 5.1.1 explains this slowdown in detail.

One question around the applicability of the Törnqvist estimates to RIIO-ED2 is whether the gains made from 2010 to 2020 could have exhausted the scope for improvements measured against the outputs included in the modelling. For example, most DNOs improved the reliability of their services across the sample period, with two DNOs reducing customers interrupted by more than half from 2010/11 to 2019/20. It may not be possible to achieve similar improvements at comparable cost going forward, which would limit the ongoing efficiencies achievable during RIIO-ED2. Some of the Törnqvist estimates could therefore overstate the scope for future improvements.

The Törnqvist modelling uses a measure of capital cost that is different from the cost base to which DNOs and Ofgem will apply the OE assumption. The Törnqvist modelling uses a measure of the cost of the capital embedded in the DNOs' networks, for reasons that Section 4.2.1 explains in detail. The OE assumption will apply to totex, which includes capital expenditure rather than the capital cost of the asset base.

Despite the differences between the measures of capital cost, the Törnqvist modelling captures important efficiency gains that are specifically relevant to capital expenditure. In particular, the Törnqvist estimates reflect efficiencies in the volume of capital used by the DNOs. If DNOs require a smaller volume of assets, they also require a lower volume of capital expenditure to construct, maintain, and replace their assets. However, the asset base measure of capital costs will not pick up any changes in the unit costs of assets (either from input price inflation or from efficiency gains) or changes in the technical lifetime of a given type of asset.

The Törnqvist estimates therefore represent the form of evidence that is most directly applicable to RIIO-ED2. They identify the productivity trends for DNOs. The estimates specifically measure the development in efficiency using several output variables that have been used for past price control reviews that are available from regulatory reporting packs submitted to Ofgem. In addition to being estimates for DNOs, they also use the most recent data available and therefore capture current trends in productivity. It is therefore an addition to the evidence base with several strengths relative to the GAA evidence that Section 3 describes.

5. Applicability of Historical Estimates to RIIO-ED2

This section surveys considerations and evidence relevant to setting the OE assumption for RIIO-ED2 that are separate from estimates of historical productivity growth. It is organised as follows:

- Section 5.1 considers three macroeconomic factors that indicate that productivity trends during the RIIO-ED2 period will be different from the historical sample periods;
- Section 5.2 surveys forecasts of UK total factor productivity growth;
- Section 5.3 reviews and critically assesses arguments specific to the electricity distribution sectors that suggest an assumption different from productivity growth in the broader economy; and
- Section 5.4 explains the impact of key developments for the RIIO-ED2 period, in particular the evolution to an expanded DSO role and the demands of meeting Net Zero.

5.1. Impact of Macroeconomic Factors on Ongoing Efficiency

Section 3 and Section 4 present evidence on historical productivity growth to inform an assumption on ongoing efficiencies achievable during RIIO-ED2. These may be inaccurate if expected economic trends during RIIO-ED2 are different from trends during the historical sample periods. This section considers three macroeconomic events that may impact productivity growth during RIIO-ED2:

- The global slowdown in productivity growth since the mid-2000s;
- The UK leaving the European Union; and
- The COVID-19 pandemic.

Each of these events are either partly or wholly outside of the sample of the historical evidence. They are all events outside of DNOs' control. Where they impact productivity growth achievable during RIIO-ED2 they therefore support setting an OE assumption that is different from the estimates of historical productivity growth.

5.1.1. Productivity slowdown since the Global Financial Crisis

Estimates of the slowdown

The UK and other advanced economies have experienced a marked reduction in productivity growth since the Global Financial Crisis of 2007-2008. As described by Ark and Venables (2020):[137]

> "The United Kingdom has suffered an extreme version of the "productivity puzzle" – the strong and largely unexplained slowdown in productivity growth among OECD economies since the mid-2000s."

The productivity slowdown is widely recognised in the academic literature. IMF researchers have found that "The drop in total factor productivity (TFP) growth following the global

[137] Ark, B. and Venables, A. J. (2020), "A concerted effort to tackle the UK productivity puzzle", *International Productivity Monitor*, vol. 39, p. 3.

financial crisis has been widespread and persistent across advanced, emerging, and low-income countries".[138] Other studies note the "recent productivity slowdown and the highly uncertain outlook for MFP growth",[139] that a "surprising and worrying feature of the economic environment in the advanced economies in recent years has been slow productivity growth",[140] and that "productivity growth rates have generally halved since 2004 across major OECD economies".[141]

The productivity slowdown indicates that estimates of productivity growth based partly or wholly on data from before the Global Financial Crisis will be higher than current productivity growth. In particular, the growth accounting estimates in Section 3 will therefore overstate the ongoing efficiencies that can be achieved during RIIO-ED2.

Growth accounting estimates for the post- Financial Crisis period demonstrate a productivity slowdown, as shown in Table 5.1. The estimates in Table 5.1 use the same sources, methods, and sample periods as used in Section 3.3. They show that GO TFP growth has been 0.5 percentage points lower after the Financial Crisis than before the Financial Crisis. This evidence suggests that TFP growth in the post-recession period has been 0.2 per cent on average.

Table 5.1: Productivity Slowdown in UK Growth Accounting Estimates

Source	ONS	Bank of England	OBR	OECD
Pre-Recession Sample	1995-2007	1998-2007	1998-2007	1985-2007
Post-Recession Sample	2010-2019	2010-2019	2010-2017	2010-2019
Pre-Recession TFP Growth	0.63%	0.75%	0.84%	0.58%
Post-Recession TFP Growth	0.21%	0.21%	0.28%	0.09%
Slowdown in TFP Growth	0.42%	0.54%	0.56%	0.49%

Notes: Arithmetic average of GO growth rates for the whole UK economy (Bank of England, OBR, OECD) or all market sectors (ONS). VA growth rates are converted to GO assuming a 46.6% primary inputs share, as explained in Section 3.1.3.
Source: NERA analysis of ONS, Bank of England, OBR, and OECD Data.[142]

[138] Adler, G. et al. (April 2017), "Gone with the headwinds: Global productivity", IMF Staff Discussion Note 17/04, p. 5.

[139] Andrews, D. et al (2016), "The global productivity slowdown, technology divergence and public policy", p. 6.

[140] Craft, N. (2018), "The productivity slowdown: is it the 'new normal'?", *Oxford Review of Economic Policy*, vol. 34, Issue 3.

[141] Goldin, I. et al. (April 2019), "The productivity paradox: reconciling rapid technological change and stagnating productivity", p. 6.

[142] ONS (19 January 2021), Multi-factor productivity estimates, Dataset MFP01, Table A10.
Bank of England (January 2020), Monetary Policy Report, Table 4.A.
OBR (13 March 2018), Productivity growth: international comparisons.
OECD (2021), Multifactor productivity (indicator). doi: 10.1787/a40c5025-en, Visited on 19 March 2021.

Relevance for RIIO-ED2

If the lower productivity trends in the economy as a whole are indicative of trends for electricity distribution, then it supports an OE assumption for RIIO-ED2 below the 0.5 per cent average of pre-recession EU KLEMS estimates. The source of the productivity slowdown remains a puzzle in economic research. It is therefore uncertain whether the reduction in productivity growth will be greater or smaller for the electricity distribution sector than for the economy as a whole.

In a report for Ofgem, CEPA noted that the UK productivity slowdown was disproportionately large in manufacturing and finance.[143] These are sectors that have been used as comparators for energy networks, including by CEPA, as Section 3.2.5 describes. This would imply that the productivity slowdown will have been greater for electricity distribution than for the broader economy. At a minimum, it indicates that the trend reduction observed in the economy and in the comparator sectors will have had an impact on the electricity distribution sector.

The CMA in its Provisional Findings for PR19 considered whether to adjust its OE estimate downwards to take account of the productivity slowdown.[144] It provisionally decided not to apply a quantitative adjustment, but instead to consider the slowdown as a qualitative factor. The CMA also provisionally found that it should only place limited weight on the slowdown.

However, the reasons the CMA gave were based on misconceptions. The CMA considered that the water sector would be less impacted than the economy as a whole, for example because it would still be able to access new capital investments given the certainty of being a regulated sector.[145] However, this example is irrelevant: capital investment is input growth, not TFP growth, and is therefore not relevant to assessing the productivity slowdown in the context of the OE assumption. It is not clear what other evidence the CMA had, except for the assumptions in companies' business plans.[146]

The CMA noted that "some forecasts have indicated that UK wide productivity growth may begin to rise over the next five years".[147] The CMA referenced forecasts of labour productivity from the OBR, presented by Europe Economics.[148] Ofgem and Europe Economics appear to be unaware that the OBR has consistently forecast rising productivity growth since its inception in 2010, as Section 5.2 explains in detail. So far every single one of the OBR's forecasts has overestimated productivity growth.[149] Given its track-record of predicting a return to higher levels productivity growth that has not in fact occurred, the OBR

143 CEPA (27 November 2020), RIIO-GD2 and T2: Cost Assessment – Advice on Frontier Shift policy for Final Determinations, p. 20.

144 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.327.

145 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.328.

146 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.328.

147 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.328.

148 Europe Economics (16 June 2020), Response to Some Key Points on Real Price Effects (RPEs) and Frontier Shift, p. 3.

149 OBR (3 March 2021), Historical official forecast database: Productivity per hour.

forecasts do not support the CMA's conclusion that the productivity slowdown is coming to an end.

The evidence on the productivity slowdown indicates that an OE assumption of 0.5 per cent based partly or wholly on pre-Financial Crisis data overstates the scope for productivity growth during RIIO-ED2. Estimates based only on post-Financial Crisis data suggest an alternative assumption of 0.2 per cent. There is some uncertainty around whether the productivity slowdown has affected the electricity distribution sector in the same way as it has affected the broader economy. However, this uncertainty is not fundamentally different from uncertainty about whether trends for comparator sectors are the same as for electricity distribution during other periods, including the sample periods for the growth accounting estimates.

5.1.2. Brexit

The UK leaving the European Union (Brexit) has the potential to reduce the productivity of the UK economy through several channels, such as:

- The introduction of trade barriers between the UK and the EU;
- Disruptions to economic activity from changes to legal and economic arrangements; and
- The diversion of management and other resources away from productive activities to preparing for and adapting to Brexit.

As part of its Economic and Fiscal Outlook, the OBR has surveyed the economic literature on the impact of Brexit on productivity.[150] It estimates that the full impact of Brexit on UK labour productivity will be 4 per cent.[151] This estimate combines both a reduction in TFP growth and capital deepening, such that the impact on TFP alone will be smaller.

The OBR further expects that the full impact of Brexit on UK productivity will take 15 years to be realised. According to its latest estimates, around two-fifths of the 4 per cent impact has already occurred by March 2021.[152] However, this impact is mostly due to "uncertainty since the referendum weighing on investment and capital deepening" rather than the expected impact on TFP.[153] Some of the adverse impact on TFP will therefore occur during the RIIO-ED1 period.

The impact on TFP will likely be smaller for electricity distribution companies than the broader economy. DNOs do not export their services, instead producing and selling services domestically. They are therefore less affected by trade barriers than firms that produce tradeable goods.

However, some of the adverse productivity shocks of Brexit will affect DNOs. Where DNOs import inputs, trade barriers and disruption to supply chains may require additional resources for international procurement. This includes increases in administrative resources going towards new visa requirements or other changes to labour laws. DNOs may also need to

[150] OBR (March 2020), Economic and Fiscal Outlook, p. 27.

[151] OBR (3 March 2021), Economic and Fiscal Outlook, p. 34.

[152] OBR (3 March 2021), Economic and Fiscal Outlook, p. 34.

[153] OBR (3 March 2021), Economic and Fiscal Outlook, p. 34.

divert management resources towards adapting to regulatory changes caused by the decoupling of the UK and EU regimes.[154]

Over a longer time horizon, Brexit may also reduce productivity growth in the electricity distribution sector by slowing the diffusion of innovations. Even if Brexit does not affect the investment and R&D spending of DNOs, it will affect other sectors' incentives and ability to innovate.[155] Reduced innovation in these sectors limits the number of innovations that can later be beneficial to electricity distribution. Reduced economic and academic interaction between the UK and the EU can also slow the spread of innovations from abroad.

Economic forecasters, including the OBR, have argued that Brexit will reduce productivity and productivity growth in the UK economy. The impact on electricity distribution will be smaller as it is a non-exporting sector. However, it will still reduce ongoing efficiencies for DNO through several channels. These changes are outside of the control of DNOs and represent external factors that reduce achievable productivity growth. While Brexit will slow TFP growth, uncertainty remains around the size of the impact, what part of the impact will affect DNOs, and how much of the impact will occur during RIIO-ED2. There is therefore insufficient quantitative evidence to pinpoint a numerical adjustment to the OE assumption.

5.1.3. COVID-19

The COVID-19 pandemic has reduced productivity in the UK economy. Government restrictions and guidelines have stopped some categories of economic activity altogether, and imposed limitations on others. This includes working from home, restricted travel, employees being required to self-isolate, employees diverting time to care work, and new anti-infection requirements for on-site work. These limitations are outside the control of DNOs and represent exogenous and disembodied productivity reductions.

The short-term effects of COVID-19 on productivity are not relevant to the RIIO-ED2 OE assumption. While uncertainty remains around the future development of the pandemic, the associated restrictions that inhibit productivity are currently expected to be largely over by the Summer of 2021.[156] If the direct, short-term impact on productivity is largely over within the initial months of 2021/22, the first year covered by the OE assumption for ED2, then it is not relevant to the OE assumption. This includes both the negative productivity shock from restrictions on economic activity, and any rebound in productivity that occurs as the restrictions are lifted or as companies adapt to limit the impact of the restrictions.[157]

[154] A Bank of England Staff Working Paper found that the Brexit process has already reduced UK productivity by between 2 per cent and 5 per cent, much of the impact due to a diversion of management resources to Brexit planning. Bloom et al. (August 2019), The Impact of Brexit on UK Firms, Bank of England Staff Working Paper No. 818, p. 2 and p. 17.

[155] Broadbent et al. (15 November 2020), "The Brexit Vote, Productivity Growth and Macroeconomic Adjustments in the United Kingdom", pp. 31-32.

[156] At the time of writing, the UK government's roadmap for the spring of 2021 plans for an end to most restrictions as part of a series of steps, the last one of which is scheduled for 21 June 2021. HM Government (February 2021), COVID-19 Response – Spring 2021, p. 39.

[157] An alternative to focusing on the long-term impact of COVID-19 would be to try to capture the short-term dynamics of productivity during the pandemic period and the immediate recovery. In order to avoid bias, this would have to include both the initial reduction in productivity as well as any subsequent recovery. However, any attempt to capture the short-term dynamics of productivity will likely suffer from a greater measurement error than a long-term approach. In

However, COVID-19 may also be a drag on UK TFP in the long-run. Both the Bank of England and the OBR has concluded that COVID-19 will have a persistent negative impact on productivity through economic scarring.[158] Economic scarring refers to mechanisms by which temporary economic shocks result in permanently reduced productivity. These include:[159]

- Loss of human capital from reduced on-the job learning;
- Loss of social capital from fewer informal interactions with colleagues;
- Diversion of management and other resources to COVID-related tasks; and
- Reductions in R&D, including in other sectors.

A recent working paper published by the Bank of England estimates the impact of COVID-19 on UK TFP across all channels. It finds that "Over the medium term, for 2022+, within-firm TFP is estimated to be around 1% lower than it would have been without the Covid-19 pandemic".[160] This indicates that economic scarring will be a drag on productivity during the RIIO-ED2 period.

The impact on productivity trends in electricity distribution will likely be smaller than on the broader economy, but still negative. As electricity distribution is an essential activity on-site work has been able to continue where necessary. However, staff have still worked from home and avoided in-person interactions where possible. A reduction in R&D in other industries will also slow the spread of innovations to the electricity distribution sectors.

The COVID-19 pandemic will therefore reduce productivity growth in the electricity distribution sector during RIIO-ED2. The overall impact will likely be smaller than the 1 per cent estimated for the economy as a whole. Given the uncertainty both around the long-term impact and the extent to which electricity distribution will be affected, there is insufficient evidence to identify a quantitative adjustment to the OE assumption. However, COVID-19 is a factor that would support an assumption below the historical estimates.

5.2. Forecasts of Productivity Growth

Ofgem has indicated that it will also consider forward-looking productivity estimates for the UK economy to inform the ongoing efficiency challenge.[161] Forecasts can be complementary to historical estimates as the type of evidence that covers the time period closest to RIIO-ED2. They can therefore indicate whether the historical estimates, which have the advantage

particular, unusual economic conditions such as entire sectors of the economy being shut down and a large portion of the labour force being furloughed would distort short-term measures of productivity during the pandemic.

158 OBR (July 2020), Fiscal Sustainability Report, p. 30.
Bank of England (August 2020), Monetary Policy Report, p. 9.

159 Haldane, A. (14 October 2020), "Is home working good for you?", speech given at the Engaging Business Summit and Autumn Lecture. Available from the Bank of England's Website. URL: https://www.bankofengland.co.uk/speech/2020/andy-haldane-engaging-business-summit-and-autumn-lecture. Visited on 25 March 2021.

160 Bloom. N. et al. (December 2020), "The impact of Covid-19 on productivity", Bank of England Staff Working Paper no. 900, p. 11.

161 Ofgem (30 July 2020), RIIO-ED2 Sector Methodology Consultation: Annex 2, para. 6.28.

of relying on a long time series and on outturn data, are reflective of the economic conditions of the immediate future.

There are few published forecasts for UK total factor productivity. Two of the institutions surveyed in Section 3.3, the Bank of England and the OBR, have issued forecasts of TFP growth as shown in Table 5.2. In GO-adjusted terms, these forecasts range from 0.0 per cent to 0.3 per cent TFP growth p.a. They are therefore consistent with the evidence in Section 5.1.1 which indicated that TFP growth since the Financial Crisis has been around 0.2 per cent. They are also in line with the estimates from the Törnqvist analysis which found that DNOs have achieved 0.2 per cent productivity growth from 2010 to 2020.

Table 5.2: Forecasts of UK TFP Growth

Forecaster	Forecast Date	Forecast Period	GO TFP Growth p.a.
Bank of England	2020	2020-2023Q1	0.0%
OBR	2018	2018-2022	0.2-0.3%

Notes: VA growth rates are converted to GO assuming a 46.6% primary inputs share, as explained in Section 3.1.3.
Source: Bank of England and OBR.[162]

While the forecasts are consistent with the other evidence, they can only be given limited weight in the overall assessment. It is not possible to effectively triangulate the forward-looking evidence due to the limited number of published forecasts. The short forecast horizon means that the estimates do not cover the RIIO-ED2 period. As the forecasts only cover a period of up to five years, they are also more likely to be affected by short-term dynamics and measurement error than the longer-term historical evidence.

Forecasts also embed further modelling assumptions and economic views compared with historical estimates based on observed outturn data. These assumptions can be systematically wrong, which will bias the forecasts.

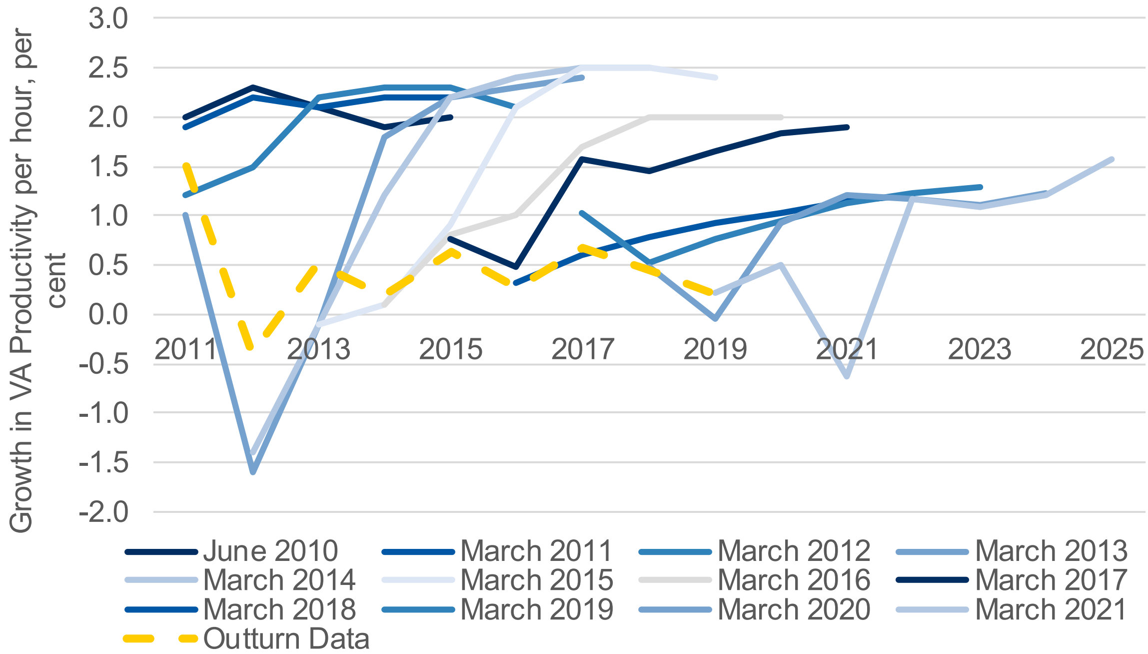
For example, the OBR's TFP forecasts shown in Table 5.2 is based on a forecast of labour productivity growth.[163] The OBR has forecast labour productivity growth over a five-year horizon every year since 2010. As a consequence of the OBR repeatedly forecasting a return to higher rates of productivity growth, its forecasts have systematically been too high.

Figure 5.1 shows the OBR's five-year forecast as of March in each calendar year since 2010. As the figure shows, the OBR has tended to revise its forecasts downwards over time (i.e. updated forecasts tend to lie below preceding forecasts in the figure). Figure 5.1 also shows that actual productivity growth (shown as the dotted yellow line) has consistently been lower the OBR's forecasts.

162 Bank of England (January 2020), Monetary Policy Report, Table 4.A.
OBR (13 March 2018), Productivity growth: international comparisons.

163 OBR (13 March 2018), Productivity growth: international comparisons.

Figure 5.1: OBR Forecasts of VA Labour Productivity Growth, 2010-2021



Notes: The chart shows the OBR's June 2010 forecast as there was no forecast in March 2010.
Source: OBR.[164]

Placing much weight on forecasts with well-known problems therefore risks introducing errors in the OE assumption. For example, ahead of RIIO-T2/GD2 CEPA advised Ofgem that:[165]

> "If we take a simple average of the forecasts for years covered by RIIO-2, the labour productivity forecasts from the BoE and OBR are 1.0% and 1.15% respectively, which is comparable to the reference value of 1.1% for opex from the EU KLEMS analysis."

Suppose that CEPA had taken this approach for assessing productivity growth ahead of the most recent five-year period for which OBR has published outturn data, which is 2015 to 2019. Using either the OBR's December 2014 or March 2015 forecasts, CEPA's approach would have found that the appropriate OE assumption on labour productivity growth was 2.1 per cent.[166] Estimated labour productivity growth for this period after the fact has turned out to be 0.4 per cent.[167] Relying on CEPA's approach to the OBR's optimistic forecasts would therefore have supported an OE assumption that was 1.7 percentage points too high.

In conclusion, forecasts of productivity growth support the conclusion that the longer-term historical estimates may overestimate the ongoing efficiencies that would be achievable in current economic conditions. However, there is limited relevant forecast evidence available.

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164 OBR (3 March 2021), Historical official forecast database: Productivity per hour.

165 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 15.

166 OBR (3 March 2021), Historical official forecast database: Productivity per hour.

167 OBR (3 March 2021), Historical official forecast database: Productivity per hour.

The forecasts that are available are shorter-term and more uncertain than the historical estimates. The OBR's forecasts also have an established tendency to overpredict productivity growth. The forecasts therefore add some but limited information about the appropriate OE assumption for RIIO-ED2.

5.3. Assessment of Alternative Evidence on Ongoing Efficiency

This section reviews and critically assesses considerations other than macroeconomic factors that have been used to support OE assumptions different from estimated historical growth. It focuses on Ofgem's Final Determinations for RIIO-T2/GD2 as the price review that is the most relevant to RIIO-ED2, but also reviews arguments presented elsewhere.

5.3.1. Benefits of innovation funding

Ofgem's approach for RIIO-T2/GD2

In its Final Determinations (FD) for RIIO-T2/GD2, Ofgem increased its OE assumption by 0.20 percentage points to reflect supposed benefits from innovation funding that network companies had accessed during RIIO-1.[168] This assumption was not based on evidence of the impact of the innovation funding. Instead, Ofgem's consultants CEPA calculated the increase in OE assumption based on "what cost savings to consumers would be required in order to make providing the innovation allowances seem a reasonable investment" over an assumed 20-year period:[169]

> "Through the innovation funding, consumers have provided the network companies with upfront allowances. Therefore, we have considered the issue from a different perspective – what would different assumptions on ongoing efficiency driven by innovation mean for the return effectively received by consumers on the innovation funding they provided to companies in RIIO-1. This can be seen as being akin to treating consumers as investors."

In effect, Ofgem has adjusted the OE assumption by whichever amount will claw-back the "upfront allowances" that it considers innovation funding to be, with interest. This type of adjustment has fundamental conceptual errors and is implemented using a biased empirical approach.

Conceptual errors

First, Ofgem did not justify the need for there to be an innovation funding adjustment. The innovation funding adjustment is intended to capture additional cost savings that companies could achieve over and above the productivity target set based on EU KLEMS estimates. It should therefore only adjust the OE assumption upwards if the RIIO-1 innovation funding exceeds the expenditure on innovation in comparator sectors.

Ofgem asserts that "the energy sector has enjoyed explicit and additional innovation funding over and above general allowances, and beyond any comparator sector", but neither Ofgem

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168 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.26.

169 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 35.

nor CEPA provide any evidence to support this.[170] Other sectors in the economy of course also invest in R&D, including R&D supported by public innovation funding. Ofgem's approach double-counts the benefits of innovation funding by adding an adjustment on top of EU KLEMS estimates.

Second, Ofgem's approach to clawing-back innovation funding through an OE adjustment distorts companies' incentives. DNOs have less of an incentive to use innovation funding in the first place if that funding will ultimately be deducted from their allowances during future periods.

Third, the innovation funding adjustment is not an objective and stable regulatory approach. Retroactively rescinding any type of funding that was granted during previous regulatory periods increases uncertainty and unpredictability for companies.

Implementation errors

Setting aside the reasons why the adjustment was unwarranted in its entirety, the way that Ofgem calculated its innovation funding adjustment included several errors and flawed assumptions. These errors consistently increased the calculated adjustment, leading to a biased OE assumption. CEPA acknowledged some of these false assumptions in its report:[171]

> "The figure of 0.2% contains some further inherent assumptions that Ofgem will have to consider in deciding to take the impact of innovation funding into account when setting an ongoing efficiency challenge:

- the only benefits that accrue to customers are cost savings – i.e. no account is taken of other benefits such as environmental benefits and quality of service; and
- no additional ongoing efficiency driven by innovation funding in RIIO-1 is already embedded in the baseline spending plans submitted by the companies."

Assuming that all innovations were aimed at (and succeeded in) achieving cost savings requires a higher adjustment to OE to claw-back the innovation funding than if only part of the funding relates to innovation driving cost savings. GDNs appealing Ofgem's FD have argued that in fact only a minority of the innovation funding was primarily aimed at achieving cost savings.[172]

Likewise, assuming that ongoing efficiencies from innovation funding were not part of companies' business plans will double-count any cost savings that are included in companies' submissions. Both assumptions therefore result in a higher assumption than a correct assumption would. However, neither CEPA nor Ofgem attempted to make any corrections.

CEPA also assumes that all cost savings would gradually emerge over RIIO-T2/GD2.[173] It is not clear why the cost savings should be perfectly aligned with the regulatory period except that this yields the maximal annual OE adjustment over RIIO-T2/GD2. Assuming instead

170 Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.26.

171 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 26.

172 See for example Cadent Gas Limited, Notice of Appeal, para. 3.137.

173 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 25.

that some of the cost savings occur before or after RIIO-T2/GD2 would result in a lower adjustment.

It is also unclear by what benchmark CEPA's innovation funding adjustment gives "consumers a reasonable return on innovation funding".[174] Ofgem applies the adjustment as a deterministic claw-back of RIIO-1 innovation funding. Consumers as "investors" therefore do not face any risks in the framework Ofgem and CEPA have put in place. The correct benchmark for a reasonable return on innovation funding in Ofgem's framework would therefore be the risk-free rate.

In its FD, Ofgem used a risk-free rate forecast of - 1.58 per cent.[175] By contrasts, CEPA's innovation funding adjustment results in a return for consumers of 4.2 per cent.[176] The innovation funding adjustment is therefore based on an assumed rate of return that is 5.8 percentage points higher than what Ofgem uses to set the network companies' allowed return. This assumed rate of return is an inconsistency that biases the innovation funding adjustment upwards.

In summary, it would not be appropriate to use an innovation funding adjustment for RIIO-ED2. The benefits of innovation expenditure are already included in the estimates of historical OE improvements. Applying an adjustment would distort DNOs' incentives to innovate. Introducing it as a retroactive claw-back of RIIO-1 funding is not consistent with objective and stable regulatory practice. Finally, any adjustment would likely be small given that the 0.20 percentage point adjustment Ofgem applied for RIIO-T2/GD2 was biased upwards by a series of errors.

5.3.2. Benefits within the RIIO framework

Efficiencies generated in previous price controls

In the RIIO-ED2 Business Plan Guidance, Ofgem suggested that "how forecasts capture enduring effects from efficiencies generated in previous price controls" is relevant to assessing ongoing efficiencies for RIIO-ED2.[177] The enduring effects of past efficiencies are not directly relevant to the OE assumption insofar as they are changes in productivity levels rather than changes in the rate of productivity growth. They should therefore be captured in two ways.

First, enduring reductions in costs achieved during previous price controls will be reflected both in DNOs' business plans for RIIO-ED2 and in the historical data available to Ofgem for cost assessment purposes. Any enduring level effects would be reflected through these channels and would result in cost savings for customers.

Second, the Törnqvist analysis in Section 4 estimates the efficiencies generated by the DPRC5 and RIIO-ED1 price controls directly. The efficiencies achieved during previous

[174] CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 25.

[175] Ofgem (3 February 2021), RIIO-2 Final Determinations – Finance Annex (Revised), p. 24

[176] It is not clear from CEPA's report whether this is a real or nominal return. The comparison assumes that it is real. CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 25.

[177] Ofgem (22 April 2021), RIIO-ED2 Business Plan Guidance, para. 5.45.

price controls therefore inform this report's recommendation of the rate of OE that will be achievable during RIIO-ED2.

Interactions with output quality

Ofgem has also identified the relevance of "interactions between ongoing efficiency forecasts and output quality" for setting the OE assumption.[178] For a given volume of outputs, ongoing efficiency improvements can take two forms:

- Reducing the costs of providing the given volume of outputs; or
- Improving the quality of outputs.

The achievable rate of OE cost savings will therefore be lower if companies are instead realising some efficiency gains as quality improvements. Both the EU KLEMS estimates in Section 3 and the Törnqvist estimates in Section 4 take account of quality improvements, and are therefore higher than they would be if measured only based on costs and output volumes.[179]

The implications of DNOs realising efficiency gains as quality improvements for the OE assumption depends on whether the quality improvements are modelled as part of the cost assessment framework for RIIO-ED2. If DNOs' allowed revenues increase as they improve output quality, then it is appropriate to set an OE assumption based on productivity growth estimates that include improvements in quality. If the quality improvements are not included as drivers as part of the cost assessment modelling, then the OE assumption applied to costs should be based only on the productivity gains estimated for the outputs that are included as drivers. This would support an OE assumption lower than estimates of productivity growth that include efficiency gains realised as quality improvements.

There is limited evidence to identify a quantitative adjustment to the OE assumptions. First, Ofgem has not yet decided on drivers for RIIO-ED2 cost assessment. It is therefore not clear which quality improvements will be omitted from this modelling. Second, while both the EU KLEMS and Törnqvist estimates attempt to take account of quality improvements, quality is difficult to measure accurately.[180] There could therefore have been quality improvements not captured by these estimates. Quality improvements not captured elsewhere in the RIIO-ED2 framework therefore give a reason to believe that an OE assumption based on historical estimates is on the high side (though it is not possible to quantify this impact).

5.3.3. Impact of monopoly structure

As part of the RIIO-T2/GD2 FD, Ofgem introduced an argument that the TSOs and GDNs should be able to outperform comparator sectors by virtue of being monopolies:[181]

> "We believe TFP and labour productivity measures from sources like the EU KLEMS could underestimate the scope for efficiency gains within regulated sectors such as

[178] Ofgem (22 April 2021), RIIO-ED2 Business Plan Guidance, para. 5.45.

[179] The Törnqvist results show that estimated efficiency growth increases when adding quality measures such as customers interrupted to the models.

[180] Section 3.2.2 describes the quality measurement errors affecting EU KLEMS estimates.

[181] Ofgem (3 February 2021), RIIO-2 Final Determinations – Core Document (Revised), para. 5.21.

> electricity and gas networks in GB. This is because, not only are network companies less exposed to negative shocks, but also the lack of competitive pressure means they should be able to place greater management focus on driving high efficiency gains. This supports an OE challenge at the top end of the range proposed by CEPA."

In one sentence Ofgem introduced two arguments for why ongoing efficiencies in regulated monopoly sectors should exceed that of the competitive sectors that it uses as comparators. Neither one can support setting an OE assumption above the evidence from comparator sectors.

First, the fact that network companies are less exposed to negative shocks does not mean that the trend in productivity is higher than in comparator sectors. It may be that ongoing efficiencies are less volatile and cyclical for electricity distribution. This does not imply that they are higher in the long run as network companies are also less exposed to positive shocks during the booms of the business cycles. Ofgem does not provide any argument, evidence or sources to substantiate a link between volatility and trend growth. There is therefore no support for the claim that regulated sectors can achieve systematically higher efficiency gains by virtue of being less cyclical industries.

Second, Ofgem's argument that a lack of competitive pressure should drive higher efficiency gains is unexplained and unevidenced. To develop an argument that could be assessed, it would need to set out a series of further steps to establish a link between a lack of competitive pressure and long-run productivity growth. Open questions include:

- Why does Ofgem believe that competition between firms is based on unproductive managerial activities rather delivering higher-quality products at lower prices?
- Why is the drain on managerial resources from the unproductive activities in competitive sectors greater than the costs of the regulatory process Ofgem imposes on DNOs?
- Why would managerial resources freed up by avoiding competitive pressure be able to achieve a sustained higher rate of efficiency gains, rather being a one-off efficiency saving?
- Would the implication of Ofgem's reasoning not be that, in the long run, consumers would be better off under a regulatory framework that did not seek to replicate competitive pressures in the way that RIIO does?
- Would Ofgem's reasoning not support the conclusions that, in the long run, all sectors of the economy would improve by being turned into legally protected monopolies not subject to competitive pressure?

Crucially, Ofgem's assertion is also contrary to mainstream economic thought. Conventional economic theory is that competitive pressure drives innovation as firms must gain efficiency advantages to stay ahead of competitors.[182] It therefore does not constitute a reason to

[182] There is a large literature on the relationship between competition and innovation. An important part of this literature builds on the work of Joseph Schumpeter and argues that a monopoly structure can incentivise greater innovation. However, these arguments have no relevance for regulated network monopolies. Large monopoly profits are the main driver of innovation in the Schumpeterian framework as firms compete on innovation in order to achieve a monopoly position. Such profits do not exist in network sectors that are subject to economic regulation. Firms in the Schumpeterian framework are also subject to competitive pressures from other firms that seek to become the monopolist of a sector. There is no comparable competitive pressure for licensed energy networks.

conclude that regulated sectors should systematically achieve higher efficiency gains than competitive ones.

5.3.4. Ongoing efficiency embedded in CPIH indexation

To enable a regulated entity to recover its costs, the change (Δ) in the output prices or average revenue (ΔR) of firm j should equal the change in its input prices (ΔIP) minus the change in its total factor productivity growth (ΔTFP):[183]

$$\Delta R_j = \Delta IP_j - \Delta TFP_j$$

This report covers ongoing efficiency, the ΔTFP term in the equation above. As at previous price controls, changes in input prices will be assessed separately as input price inflation (the sum of general inflation and real price effects (RPEs)). Ofgem has decided to index RPEs at RIIO-ED2 rather than setting ex ante allowances.[184] Ofgem intends to use general consumer price inflation rather than specific factor price indices where it does not believe that doing so materially affects the determined RPEs.[185]

At RIIO-2, Ofgem is adopting the CPIH index for general inflation instead of the RPI indexation used at previous price controls.[186] This has implications for the profile of the recovery of revenues as well as the allowances for cost items indexed over time to Ofgem's preferred measure of inflation within the price control period.

However, Ofgem and its advisers CEPA appear to also believe that changes to input price indexation interacts with the OE assumption:[187]

> "The RIIO-2 draft determinations for gas distribution and transmission also set out our intention to apply an ongoing efficiency challenge to all components of totex as default position, including cost categories that are not subject to RPE indexation. Indeed, using the CPIH index for general inflation (instead of RPI) for costs without RPE indexation may already embed efficiency improvements. However, we followed CEPA's conclusion that it was not possible to determine any significant detrimental impact of applying ongoing efficiency assumptions to these cost areas."

Changes to cost indexation is not a reason to set a different OE assumption. OE and input price inflation are conceptually distinct. Ongoing efficiencies are changes to the volume of inputs that a DNO needs to use to produce a given volume of outputs. Real price effects are changes to the unit prices of inputs (relative to general inflation). The rate at which DNOs convert inputs into outputs is not affected by a regulatory decision on how to treat input price inflation.

For an exposition of a Schumpeterian framework, see for example Aghion, P. et al (2005), "Competition and innovation: An inverted-U relationship", *Quarterly Journal of Economics*, vol. 120, no. 2, pp. 701-728.

183 This of course assumes that the regulated entity's output prices start from an initial level that allow it to recover its costs.

184 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Annex 2, Table 2.

185 Ofgem (30 July 2020), RIIO-ED2 Sector Methodology Consultation: Annex 2, para. 6.14.

186 Ofgem (30 July 2020), RIIO-ED2 Sector Methodology Consultation: Annex 2, para. 6.26.

187 Ofgem (30 July 2020), RIIO-ED2 Sector Methodology Consultation: Annex 2, para. 6.26.

A change to CPIH indexation therefore does not have an impact on the correct OE assumption. Instead, it is a question of using an approach to input price inflation that adequately reflects the input price pressures faced by DNOs. Given that CPIH is systematically different from RPI, Ofgem will need to reassess the appropriate RPEs assumption for cost items that will be indexed to CPIH rather than factor input price indices.

5.3.5. Embodied efficiencies

Embodied technological change, or input quality change, refers to productivity gains from employing new inputs over and above the gains obtainable from a comparable amount of pre-existing inputs.[188] This could be technological improvements in new vintages of physical inputs such as plant and equipment purchased and used by DNOs. It can also take the form of a better educated and more productive labour force. It is distinct from disembodied technological changes which are improvements in the process by which firms use inputs of any given quality to produce outputs.

Some approaches to measuring total factor productivity growth attempt to only estimate disembodied technological change. Regulators, including Ofwat, have argued that embodied technological change represents a type of OE that is additional to the OE captured by estimates that only cover disembodied technological change.[189] Based on this, they have reasoned that OE assumptions should be set at a higher level than estimates of disembodied technological change to reflect the additional productivity improvements made possible by increases in input quality.[190] This subsection explains both conceptual and practical errors in applying such an adjustment, focusing on Ofwat's PR19 Final Determinations.

Conceptual errors

At PR19, Ofwat determined that it should adjust its OE requirement upwards to reflect embodied technical change that it assumes are not included in EU KLEMS estimates.[191]

> "The estimates exclude embodied technological change, which are the quality improvements in inputs. Europe Economics cites a study which indicates that taking into account quality improvements could lead to as much as 60% increase in productivity[sic.]."

It its Provisional Findings and its Final Report, the CMA accepted the principle of the adjustment proposed by Ofwat and Ofwat's consultants Europe Economics, but not the 60 per cent number itself:[192]

> "We agreed with Europe Economics that the EU KLEMs TFP data used in the comparator analysis did not seek to measure changes in productivity growth resulting

[188] Sakellaris, P. and Wilson, D. (July 2002), "Quantifying embodied technological change", ECB Working Paper no. 158, p. 5.

[189] Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 180.

[190] Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 180.

[191] Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 180.

[192] CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.342.
CMA (17 March 2021), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Final report, para. 4.553.

from changes in embodied technical change. This is because the EU KLEMS productivity measure we relied on sought to measure disembodied technological change with embodied technical change already accounted for by input price changes."

The problem with the CMA's reasoning is that the operative word is "seek". In theory, the aim of the EU KLEMS methodology is to capture quality changes in its input price indices instead of in the TFP estimates. As Section 3.2.2 explains, in practice measuring quality is a weakness of EU KLEMS estimates. Because EU KLEMS data mis-measures changes in input quality, its estimates of productivity growth therefore do contain the impacts of embodied technical changes. This has been a driver of the high EU KLEMS estimates of technological growth in sectors such as telecommunications, as Section 2.4.2 explains.

The CMA is therefore wrong to assume that EU KLEMS estimates only include disembodied technological change. In practice, they also include the embodied technological change. By adding an adjustment for embodied technological change on top of the EU KLEMS estimates, Ofwat and the CMA therefore double-counts embodied technological change.

Applying any kind of adjustment for embodied technical change also requires careful attention to the relationship between improvements in input quality and changes to input prices. The RIIO-ED2 OE requirement will be applied to monetary costs, not input volumes. Improvements in input quality therefore only translate to efficiency savings for DNOs if they are not matched by increases in the price of inputs. Any attempt to adjust the OE assumption to reflect changes in input quality must therefore also analyse how changes in input quality feed through to the indices used to determine RPEs.

Estimation errors

The method that Ofwat and Europe Economics used to arrive at the 60 per cent figure is also fundamentally flawed. Ofwat's claim that Europe Economics "cites a study which indicates that taking into account quality improvements could lead to as much as 60% increase in productivity" is simply false.[193] No such study exists. Instead, Europe Economics derives the number by combining two different studies:[194]

- Uri (1983), from which Europe Economics takes the stylised fact that technical progress is 50 per cent disembodied and 50 per cent embodied technical change; and[195]
- Hulten (1992), from which Europe Economics takes the stylised fact that embodied technical change accounts for 20 per cent of the TFP growth estimated by growth

193 Ofwat (December 2019), PR19 final determinations - Securing cost efficiency technical appendix, p. 180.

194 What Europe Economics says about the conclusion it draws from Uri (1983) is that "disembodied and embodied technical change are of similar orders of magnitude". The assumption it uses in its calculations is that disembodied and embodied technical change are exactly as large.
Europe Economics (11 July 2019), Real price effects and frontier shift – Updated assessment, p. 64.

195 Uri (1983), "Embodied and disembodied technical change and the constant elasticity of substitution production function", *Journal of Applied Mathematical Modelling*, vol. 7, no. 6, pp. 399-404

accounting studies and that disembodied technical change accounts for the remaining 80 per cent.[196]

Europe Economics calculates the 60 per cent adjustment in two steps. First, it takes the stylised fact from Uri (1983) that embodied technical change is as large as disembodied technical change. Second, it takes the stylised fact from Hulten (1992) that disembodied technical change is 80 per cent as large as estimated TFP growth. Embodied technical change must therefore also be 80 per cent as large as estimated TFP growth. Europe Economics therefore concludes that the sum of embodied and disembodied technical change must be 160 per cent as large as estimated TFP growth. It therefore applied a 60 per cent upwards adjustment to estimated TFP growth.[197]

The poor quality of the limited evidence that Europe Economics cites undermines its calculations. Both studies are several decades old, based on US data, and relate only to quality improvements in capital. Their results cannot therefore be uncritically applied to the UK, to all factors of production, and to the RIIO-ED2 period.

In particular, the results from Uri (1983) warrant no confidence as estimates relevant to RIIO-ED2. The study relied on US data from 1947-1980, although the author concludes that no inferences should be made from the data for 1971-1980.[198] Effectively, the most recent data point estimate is therefore over 50 years old.

The estimates contained in Uri (1983) demonstrate the danger of transferring them to the context of RIIO-ED2. Uri (1983) finds TFP growth of 3 per cent p.a., and then a further 3-4 per cent growth from embedded technical change in capital alone.[199] If taken seriously, this would support an OE assumption of at least 6 per cent annual growth. This is several times higher than any of the estimates from UK regulators, international regulators, academic researchers, network companies, institutions and other sources surveyed in this report. It demonstrates that the results from Uri (1983) are not an indication of current economic trends. By relying on the specific results cited in this paragraph to derive its first stylised fact, Europe Economics bases its adjustment on unreliable evidence.

The CMA provisionally rejected the proposed quantitative adjustment on the grounds that the evidence provided was too unreliable.[200] However, the implication of the poor quality of the evidence is not only that 60 per cent estimate cannot be relied upon, but also that it does not even support the sign of any adjustment. For stylised facts somewhat different from the ones from the unreliable Uri (1983) and Hulten (1992) studies, Europe Economics' approach

196 Hulten (1992), "Growth Accounting When Technical Change is Embodied in Capital", *American Economic Review*, vol. 82, no. 4, pp. 964-980

197 What Europe Economics says about the conclusion it draws from Uri (1983) is that "disembodied and embodied technical change are of similar orders of magnitude". The assumption it uses in its calculations is that disembodied and embodied technical change are exactly as large.
Europe Economics (11 July 2019), Real price effects and frontier shift – Updated assessment, p. 64.

198 Uri (1983), "Embodied and disembodied technical change and the constant elasticity of substitution production function", *Journal of Applied Mathematical Modelling*, vol. 7, no. 6, p. 404

199 Uri (1983), "Embodied and disembodied technical change and the constant elasticity of substitution production function", *Journal of Applied Mathematical Modelling*, vol. 7, no. 6, p. 404

200 CMA (29 September 2020), Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations: Provisional findings, para. 4.343.

would have calculated a zero or negative adjustment. In the absence of reliable evidence, there cannot therefore be a presumption that there must be a positive adjustment.

Finally, the estimates of the ongoing efficiencies achieved by the DNOs over the period 2010-2020 (presented in Section 4) do not distinguish between embodied and disembodied efficiency gains. These would therefore not in any case need to be adjusted to reflect embodied technical changes. Furthermore, since the Törnqvist estimates include both embodied and disembodied technical change, if there were embodied technical improvements not captured in the EU KLEMS estimates we would expect the Törnqvist analysis to estimate higher ongoing efficiencies than the EU KLEMS analysis. Instead, the results from the Törnqvist modelling are broadly consistent with and in fact lower than the EU KLEMS estimates. This suggests that embodied technical change has not driven embodied efficiency gains over and above what is captured in the EU KLEMS estimates.

There is no good evidence to suggest that the estimates derived in this report should be adjusted upwards to reflect embodied technical change. While the EU KLEMS estimates seek to exclude embodied efficiencies, in practice they include changes in input quality and hence include some embodied efficiencies. An analysis of input quality also cannot be divorced from the analysis of input prices. The calculation of embodied technical change for PR19 was fundamentally flawed, relying on evidence not applicable to PR19 or indeed RIIO-ED2. Finally, the Törnqvist estimates would include any embodied efficiencies, but despite this they are not on the high end of the evidence surveyed.

5.3.6. Estimates from Ajayi et al. (2018)

Ofgem has commissioned a report from the Energy Policy Research Group to analyse historical productivity growth in electricity and gas networks in the years since privatisation (Ajayi et al. (2018)).[201] Ajayi et al. (2018) therefore has a similar objective to this report's Törnqvist analysis. Ofgem highlighted the study as an example of a methodology to estimate historical performance in the DNO sector.[202] This section reviews and critically assesses the evidence from Ajayi et al. (2018).

Ajayi et al. (2018) uses a Malmquist approach based on DEA to estimate the change in the ratio of outputs to inputs for DNOs from 1990 to 2017.[203] The study uses the same scale and quality outputs as the Törnqvist analysis in Section 4, but also includes energy losses and customer satisfaction as outputs in one model specification each.[204] The study's base model finds that the geometric mean of TFP growth was 1.1 per cent p.a. across the sample period:[205]

> "We find that electricity distribution sector shows TFP grows by 34% over the whole period (1990/91-2016/17) using a base model which does not include any quality

201 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 1.

202 Ofgem (30 July 2020), RIIO-ED2 Sector Methodology Consultation: Annex 2, para. 6.40.

203 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 2.

204 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 32.

205 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 2.

> variables. Adding quality variables in general improves measured productivity growth."

There are fundamental problems with the study such that it does not provide any reliable evidence for the level of OE that will be achievable during RIIO-ED2. One conceptual problem is that the study uses expenditure measures of inputs, including capex. As the authors acknowledge, this results in productivity being measured with error due to volatility and trends in investments:[206]

> "A suspected reason for low measured productivity is that energy networks have needed to invest heavily to respond to government objectives for the addition of renewables and the promotion of energy efficiency without seeing increased measured outputs."

Ofgem's consultants CEPA assessed the reliability of Ajayi et al. (2018) in the context of the RIIO-T2/GD2 OE assumption. CEPA cited the use of capex rather than a measure based on the capital stock or flow of capital services as a reason not to rely on the study for RIIO-T2/GD2.[207] Ofgem consequently did not use the study's estimates.

The authors also emphasise the poor quality of the data that the study uses in its Malmquist analysis:[208]

> "The data was surprisingly difficult to collect given the emphasis that GB energy regulatory agencies (Offer, Ofgas and Ofgem) have had on using data within price controls to undertake benchmarking. The gas data was particularly poor.
>
> A key learning was the surprisingly poor quality and consistency of the ONS data over time. We suggest that Ofgem work with the ONS to improve these important national statistics via collecting them from energy companies as part of their licence conditions."

Measurement error in the data translates to errors in the study's results. Inconsistencies in the data have the potential to bias estimates as level shifts in either inputs or outputs will affect the observed productivity trends.

The problems of the study are evident in the year-on-year results. The headline result of 1.1 per cent growth p.a. conceals the variation in year-on-year growth rates. For example, the base model estimates that there are two years with industry-average productivity growth of more than 30 per cent in a single year.[209] These are implausibly high estimates of productivity changes in a single year. The implausible results undermine the reliability of the results more broadly in two ways.

First, the implausible year-on-year movements illustrate the scale of the errors in the study. They could result from the factors discussed above, such as volatility in capex or

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206 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 2.

207 CEPA (27 May 2020), RIIO-GD2 and T2: Cost Assessment – Frontier shift methodology paper, p. 18.

208 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 3.

209 2000/2001 and 2005/2006.
Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, Table 5.

inconsistency in the data. There could also be other sources of error that have not been identified. These factors are apparent in the large single year movements but are also embedded in the modelling more broadly and can affect results in less obvious ways.

Second, even ignoring the potential for errors in the results more broadly, the growth rates for the two outlier years are so large that they drive the overall results. The cumulative TFP growth from 1990 to 2007 in the base model is 34 per cent when including the two outlier years. It is - 23 per cent, or - 1.0 per cent p.a., when excluding the two outlier years. Since the results are driven by the outliers, they are not reliable evidence that should be used for RIIO-ED2.

Results from Ajayi et al. (2018) will also be misleading for the OE achievable during RIIO-ED2 because they embed privatisation effects. The study surveys the literature on utility privatisation internationally and finds that privatisation is usually followed by a period of increased productivity growth.[210] Ajayi et al. (2018) find that in the years following privatisation British DNOs achieved greater productivity growth than the long-term average.[211] Privatisation was a one-off event, and the resulting productivity gains would not be replicable during RIIO-ED2. Because Ajayi et al. (2018)'s estimates include the immediate post-privatisation period, they will therefore overstate the scope for OE during RIIO-ED2.

There are some qualitative conclusions from Ajayi et al. (2018) that are consistent with the evidence surveyed in this report. First, the study finds that productivity growth was higher before 2010 than it has been since 2010.[212] This is in line with the findings on the productivity slowdown discussed in Section 5.1.1. Second, the study finds that observed DNO productivity growth is higher when the modelling includes quality outputs, consistent with the findings in Section 4.[213] However, given the limitations of Ajayi et al. (2018), it only provides limited support to these conclusions.

In summary, the estimates from Ajayi et al. (2018) are not suited to informing the RIIO-ED2 OE assumption. The study relies on capex rather than capital stock measures of cost and suffers from the poor quality of the available data. The underlying results are volatile and implausible. Estimates that include the privatisation effect will also overstate the improvements that are feasible during RIIO-ED2. Some conclusions on the productivity slowdown and on improvements in output quality are consistent with other evidence but can only be given limited weight in light of the study's problems.

5.4. Developments for RIIO-ED2

DNOs will meet a range of new requirements, and deliver several new outputs, in RIIO-ED2. While DNOs' operating environment has changed across previous price controls, Ofgem has indicated that it expects RIIO-ED2 to be the start of a transformational period for the electricity distribution sector. It has highlighted Net Zero and an expanded distribution

210 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 21.

211 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, Table 5.

212 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, Table 16.

213 Ajayi, V. et al. (21 December 2018), Productivity growth in electricity and gas networks since 1990, p. 2.

system operator (DSO) role as two areas where it is implementing new arrangements to facilitate the DNOs' increased responsibilities.[214]

Ofgem expects that enabling Net Zero will put a series of new demands on DNO:[215]

> "A key objective of RIIO-ED2 is to support the delivery of Net Zero at the lowest cost to the consumer. The various pathways to Net Zero indicate that electricity demand will grow significantly, as consumers increasingly rely upon the electricity networks for their power, light, heating and transport. This will place additional demands on the local grids and in some instances, this will exceed existing capacity unless the DNOs take action."

Ofgem has also indicated that DNOs will increasingly need to take on DSO functions, effectively taking on an expanded role in managing the flows of energy across their networks.[216] Ofgem has specifically identified four strands where it will require DNOs to evolve towards a new DSO role:[217]

- New requirements on DNOs to collect and manage system data;
- New regulations and role definitions specifying DSO functions that DNOs will be required to undertake;
- New and evolving institutional arrangements to implement DSO governance arrangements; and
- New arrangements to require that DNOs take into account whole-system impacts when operating distribution networks.

Where DNOs are required to deliver new outputs, performance against efficiency targets based on existing outputs will deteriorate. Section 5.3.2 explains the trade-off between realising ongoing efficiencies as cost savings or as improvements in output quality. Likewise, companies face a trade-off between realising productivity growth in the form of cost reductions or in the form of new outputs. The Net Zero and DSO agendas represent important new sets of outputs. They therefore reduce the ongoing cost efficiencies achievable during RIIO-ED2.

The Australian case study in Section 2.4.1 demonstrates that the impact of new and unmodelled outputs on measured productivity can be large and negative. The AER's modelling found that average opex productivity in the distribution industry had declined by 3.41 per cent p.a. from 2006 to 2012.[218] The AER found that this was not a reduction in operational efficiency. Instead, the low measured efficiency gains reflected "the significant new regulatory obligations that distributors were required to meet, and which required significantly increased opex, but with no change in measured output".[219]

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214 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Overview, paras. 1.6-1.21.

215 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Overview, para. 4.1.

216 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Overview, para. 5.1.

217 Ofgem (17 December 2020), RIIO-ED2 Sector Methodology Decision: Overview, para. 5.2.

218 AER (March 2019), Final decision paper: Forecasting productivity growth for electricity distributors, Table 3.

219 AER (November 2018), Draft decision paper: Forecasting productivity growth for electricity distributors, p. 10.

The new Net Zero and DSO obligations that Ofgem will impose in RIIO-ED2 will require DNO resources both in the form of increased monetary costs and through the deployment of DNO staff and management. They will therefore reduce the ongoing efficiencies as calculated against measured outputs that are achievable during RIIO-ED2. This implies that estimates of historical OE are likely to be higher than the appropriate OE assumption for RIIO-ED2.

6. Conclusions

This report surveys a wide range of evidence to inform an OE assumption for RIIO-ED2, including:

- Estimates of growth in total factor productivity in comparator sectors available from the EU KLEMS database for the years 1970-2007. This report uses Gross Output measures of productivity growth as the alternative Value Added estimates are inconsistent with a totex framework and therefore unsuitable for the RIIO-ED2 OE assumption;
- Modelling of the efficiency improvements that DNOs have achieved from 2010/11 to 2019/20 estimated using a Törnqvist approach. NERA estimated this Törnqvist index directly from information provided by participating ENA members;
- Estimates of economy-wide productivity growth published by economic research institutions based on growth accounting approaches (GAA). This report considers long-term historical estimates and estimates based on data since 2010 separately to account for the reduction in productivity growth observed globally since the Global Financial Crisis (GFC) of 2007-2008; and
- Forecasts of productivity growth available from the Bank of England and the Office for Budget Responsibility.

This section summarises the evidence presented in this report. It critically assesses each source of evidence against the four criteria set out in Section 2.1 and draws conclusions.

The mean **EU KLEMS** estimate is 0.5 per cent, with a range of estimates from 0.3 to 0.8 per cent. EU KLEMS has the advantage of relying on the longest time series of data. DNOs cannot influence the estimates, so this approach does not distort incentives. The evidence is also disaggregated by sector which enables us to triangulate the estimates, improving reliability and reducing subjectivity.

However, the need to use comparator sectors requires a degree of subjectivity even when relying on a balanced reading of a broad selection of evidence. It also reduces accuracy if the trends for comparator sectors do not match those in electricity distribution. Older EU KLEMS data could also be inaccurate indicators of current trends, due to changes in the pace of productivity improvement over time. EU KLEMS estimates also contain known inaccuracies and errors. Finally, the EU KLEMS estimates do not separate between OE and catch-up, although this weakness is mitigated by having a long time series.

The mean estimate for OE growth from the **Törnqvist analysis** is 0.2 per cent. The range of estimates across the five model specifications is -0.1 to 0.4 per cent. The Törnqvist estimates are the most accurate indicators of current trends for DNOs as the estimates are based on historical DNO productivity growth, and on the most recent data available.

As the Törnqvist estimates use industry average results they do not explicitly distinguish between OE and catch-up, which is somewhat mitigated by having a 10-year sample period. The Törnqvist approach requires some judgement when selecting model specifications, which is reduced by using statistical criteria to select models and by relying on a range of model specifications. The Törnqvist estimates are the one source of evidence that DNOs have some control over, although the influence of any one DNO or network company is limited.

The mean of the **long-term GAA estimates** from institutional sources is 0.4 per cent, with a range of 0.3 to 0.5 per cent. Like the EU KLEMS estimates they have the advantages of relying on a long time series, which mitigates but does not eliminate the influence of catch-up efficiency, and of being outside of DNO control. The estimates are aggregates for the broader economy, which limits subjectivity in selecting estimates but also means they may be less accurate reflections of trends specific to the electricity distribution sector. Estimates based on older data may also not reflect current trends as accurately as more recent evidence.

The **GAA estimates from institutional sources averaged over the years since the Global Financial Crisis of 2007-2008** have a mean of 0.2 per cent, and a range of 0.1 to 0.3 per cent. The more recent data may be a better reflection of current economic trends in light of the observed slowdown in productivity growth. However, the shorter sample period increases the risk that catch-up and cyclical effects impact the estimates.

The mean of the **forecasts** surveyed in 0.1 per cent, within a range of 0.0 to 0.3 per cent. The forecasts are based on assumptions rather than actual economic data which reduces their reliability. TFP forecasts are only available from a limited number of sources, and they cover short forecast periods. Some forecasts, such as those published by the OBR, also have a track-record of being systematically too high, prompting large downward revisions over successive forecasts.

While the forecasts are forward-looking, they do not cover the same period as the RIIO-ED2 OE assumption. They are also economy-wide forecasts, thereby not targeted at trends for electricity distribution and not separating ongoing efficiencies from catch-up. Because the forecasts are based on modelling assumptions, they embed the subjectivity, judgements and assumptions of the forecasters. Because they are subject to material revisions over time, the assumptions that would result from the forecasts can be sensitive to the exact forecast used.

The different sources of evidence are complementary. The estimates come from both growth accounting and Törnqvist approaches. Some estimates use data from the broader economy (GAA, forecasts, some EU KLEMS), while others identify trends specific to electricity distribution and selected comparator sectors (Törnqvist analysis, some EU KLEMS). Some sources rely on decades-long time series to identify long-term trends (EU KLEMS, long-term GAA) while others use sample periods that are closer and more relevant to RIIO-ED2 (Törnqvist analysis, post-GFC GAA, forecasts).

Table 6.1 summarises the estimates from each source of evidence and their performance against the four criteria for a good approach. The EU KLEMS and Törnqvist approaches perform well on the criteria, followed by the institutional GAA estimates. The forecasts are weaker evidence as assessed against the criteria. However, to avoid inserting subjectivity into the analysis, this report does not implement an explicit weighting of the estimates.

Table 6.1: Summary and Assessment of the Evidence

Evidence	Captures trends in productivity for DNOs	Separates OE and catch-up	Objective and stable over time	Does not distort incentives	Range of estimates	Mean of estimates
EU KLEMS	◕	◕	◕	●	0.3-0.8%	**0.5%**
Törnqvist	●	◑	◕	◕	-0.1-0.4%	**0.2%**
Long-Term GAA	◑	◕	◕	●	0.3-0.5%	**0.4%**
Post-GFC GAA	◕	◑	◕	●	0.1-0.3%	**0.2%**
Forecasts	◔	◑	◑	●	0.0-0.3%	**0.1%**

Notes: Each criterion ranked on a four-point scale from worst (quarter-full red) to best (full dark green).
Source: NERA analysis.

As can be seen from Table 6.1, the alternative sources of evidence have their relative strengths and weaknesses. For instance, as the only index that tracks inputs and outputs of DNOs directly, the Törnqvist index may be most effective at capturing trends in productivity for DNOs. However, comparable data was available for a shorter time period than the EU KLEMS data or long-term GAA. Volatility in productivity growth and systematic movements in DNOs' productivity relative to the efficient frontier may therefore be more likely to affect results from the Törnqvist indices we estimated. Given the differing merits of the different sources of evidence we present in Table 6.1, the most representative OE assumption is likely to draw on the range of evidence in Table 6.1.

The single OE assumption for RIIO-ED2 most consistent with the evidence presented in the Table above is 0.3 per cent p.a. This is the mid-point of the range of mean estimates for each of the evidence categories. 0.3 per cent p.a. is also the only assumption that is consistent with the range of estimates within every category of evidence. It is therefore the conclusion that is best supported by a balanced reading of the body of evidence. It is consistent with the range of estimates of DNO productivity improvements since the start of DPCR5 as estimated by the Törnqvist modelling.

The 0.1 to 0.5 per cent range of mean estimates defines the widest range of assumptions that could reasonably be derived from the evidence. An OE assumption outside of this range would be inconsistent with the sources of evidence presented in this report.

An assumption at the 0.1 per cent bottom of the range is consistent with the range of estimates from the sources based on more recent data (Törnqvist analysis, post-GFC GAA, forecasts). It could therefore be supported by placing more weight on current economic conditions. By contrast, an assumption at the 0.5 per cent top of the range is consistent only with the range of estimates within the two categories of evidence based on longer historical time series (EU KLEMS, long-term GAA). An estimate towards the top of the range would therefore require placing more weight on estimates of long-term trends.

The 0.3 per cent OE assumption recommended in this report is lower than some assumptions used in previous price control reviews, although in line with recent international precedent. The difference is driven by three factors:

- We have presented new evidence not considered before in the form of the Törnqvist analysis, which indicates that the rate of achievable ongoing efficiencies for DNOs is lower than previously assumed;
- Some earlier price control reviews have erroneously placed weight on Value Added measures of productivity growth. These are inconsistent with a requirement on totex, and result in OE assumptions that are biased upwards. As such they are not suitable for use in the context of the RIIO-ED2 regulatory framework, and correctly using Gross Output measures instead results in a lower assumption; and
- We have reviewed recent evidence that economy-wide productivity growth has been slower in the decade since the Global Financial Crisis of 2008-2009 than in the historical period used in estimates of long-term productivity growth.

This report also reviews and critically assesses evidence indicating that the ongoing efficiencies that will be achievable during RIIO-ED2 will be different from the historical evidence presented -in Table 6.1. Factors that suggests that the historical estimates are too high for RIIO-ED2 include:

- The fact that the historical estimates incorporate some catch-up efficiency gains in addition to ongoing efficiencies;
- The reduction in productivity growth from the UK leaving the EU;
- The negative impact on productivity growth of the COVID-19 pandemic;
- DNOs realising efficiency gains as quality improvements or outputs not included in the RIIO-ED2 cost assessment modelling rather than as totex reductions; and
- DNOs being required to deliver new outputs during RIIO-ED2, including as part of the Net Zero agenda and as part of a move towards an expanded DSO role.

Although it is not possible to precisely quantify the impact of these factors, they do suggest that the level of annual OE improvement that DNOs can expect to achieve until the end of the RIIO-ED2 control may be lower than the 0.3 per cent mid-point estimate. The report also surveys several arguments that have been advanced in favour higher OE requirements, such as Ofgem's proposed RIIO-T2/GD2 innovation funding adjustment. However, there is no reliable evidence to suggest that these apply to RIIO-ED2. The evidence presented in this report shows that, on balance, an OE growth assumption of 0.3 per cent per annum could be a high target for DNOs from 2021/22 to 2027/28.

Appendix A. Technical Description of Törnqvist Modelling

This appendix supplements Section 4's description of the Törnqvist analysis. Section 4 explains the modelling steps and methodological decisions. This appendix provides additional notes on the technical details of the modelling. As with the rest of the report, the purpose of the methods described in this is strictly limited to informing the OE assumption. It does not contain any recommendations for other aspects of the RIIO-ED2 methodology.

A.1. Data Collection and Processing

A.1.1. Opex data

The modelling uses operating costs from each DNO's statutory accounts, as provided to NERA by the companies. The measure of statutory opex used is net of exceptional items, depreciation and amortisation.

The modelling adjusts the statutory opex for two DNOs to account for a change in accounting practices during the sample period. The DNOs in question changed the assumed accounting capitalisation for external services partway through the period. The reduced capitalisation led to a jump in this category of statutory opex. Without a revision to the data, this accounting change would have appeared as a drop in productivity in the Törnqvist analysis. NERA and the DNOs therefore agreed to adjust the external services data prior to the accounting change to construct a consistent time series. We achieved this by calculating the difference in expenditure on external services between the first year after the change and the last year prior to the change. Adding this difference to the data for the years prior to the change reduced the risk of bias from the change in accounting standards.

The modelling subtracts regulatory pass-through costs from each DNO's statutory opex. For all DNOs other than SSEH it uses pass-throughs as defined as total gross costs in the Cost and Volumes RRP, Table C22. For SSEH the modelling does not deduct pass-through costs associated with Shetland. As the regulatory accounting treatment of the Shetland costs changed between DPCR5 and RIIO-ED1, deducting these costs would risk creating artificial movements in opex.

The Törnqvist modelling uses costs measured in 2012/13 prices. This is the price base used for RIIO-ED1. DNOs' statutory accounts are available as nominal data. The modelling therefore deflates statutory opex by a measure of factor price inflation. This takes account of both general economy inflation (RPI) and any real price effects (RPE) that affect DNOs' operating costs.

The modelling uses a factor price index calculated using Ofgem's approach to real price effects for RIIO-ED1. It uses the input price indices that Ofgem used for the FD RPE assumption.[220] It weights each input type (e.g. general labour, specialist labour) according to the notional cost structure Ofgem used for the faults, tree cutting, and controllable opex expenditure categories for RIIO-ED1.[221] It weights the input mixes across the faults, tree

[220] The modelling does not use the LNKY AEI index for general labour as this was superseded by the K54V AWE index. Ofgem (28 November), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment – Final Decision, Table 12.2.

[221] Ofgem's FD did not specify the split between opex and capex within the faults expenditure category for inputs other than materials. The modelling therefore splits the two largest input categories, general labour and specialist labour,

cutting, and controllable opex categories according to the cost area weighting for the totex RPE as published by Ofgem.[222] Table A.1 shows the weighting of each input price index according to this methodology.

Table A.1: Summary of Input Price Indices

Source	Expenditure Category	Index Name	Weight Within Category	Weight Within Opex
ONS	General Labour	K54V AWE private sector including bonus	100%	52.9%
BEAMA	Specialist Labour	Electrical labour	50%	10.2%
BCIS	Specialist Labour	70/1 Labour and supervision in civil engineering	50%	10.2%
BCIS	Materials Opex	FOCOS RCI infrastructure: materials	100%	9.1%
ONS	Plant and Equipment	K389 Machinery and equipment output PPI	50%	2.8%
BCIS	Plant and Equipment	70/2 Plant and road vehicles: providing and maintaining	50%	2.8%
ONS	Transport and Other	Retail Price Index	100%	12.0%

Source: NERA analysis using Ofgem approach.[223]

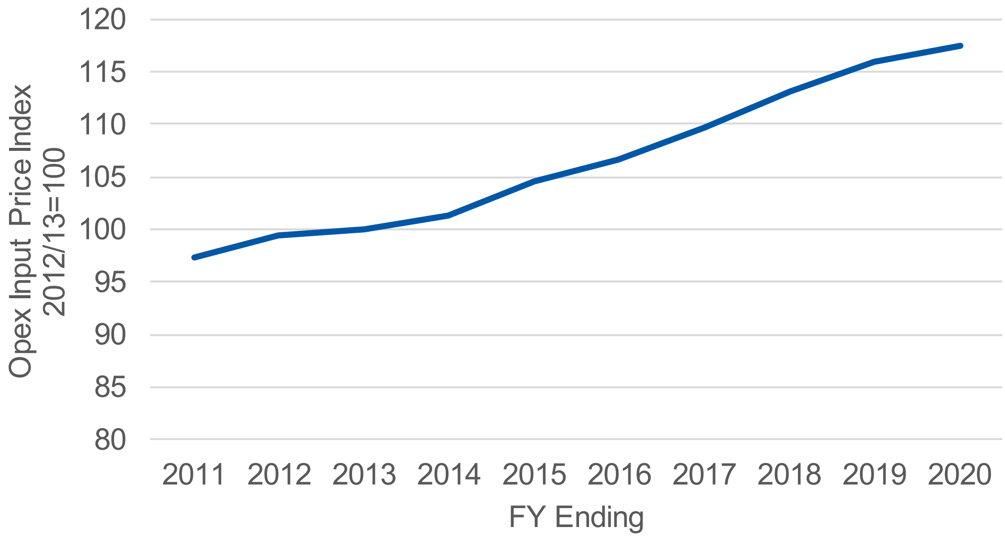
The data uses index values for March of each fiscal year. Figure A.1 shows the resulting opex input price index. The modelling deflates nominal opex by the input price index to derive operating costs in a 2012/13 price base.

between opex and capex based on the opex-capex split in these categories in the notional cost structure Ofgem published in its DD. For the plant and equipment and other categories the modelling assumes that the costs included in the notional structure all relate to operating costs.
Ofgem (28 November), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment – Final Decision, Table 12.4.
Ofgem (30 July 2014), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment, Table 12.2.

222 Ofgem appears not to have published the weighting for the FD. The modelling therefore uses the weighting published as part of the DD.
Ofgem (30 July 2014), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment, Table 12.3.

223 Ofgem (28 November), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment – Final Decision, Table 12.2

Figure A.1: Opex Input Price Index



Source: NERA analysis of ONS, BEAMA, and BCIS data using Ofgem approach.[224]

A.1.2. MEAV data

The Törnqvist modelling uses the MEAV of each DNO to calculate the annual cost of the capital embedded in their networks. It sources each DNO's asset register from the Cost and Volumes Table M15 – MEAV.

Year-on-year movements in the asset volumes reported as part of MEAV in Table M15 do not only reflect additions and disposals. There are also changes due to cleansing – updates to the asset register to correct inaccuracies that DNOs identify in their asset registers. Cleansing data is available from the Cost and Volumes Table V2. These changes vary in magnitude both across companies and across years, with some years seeing larger revisions.

Changes to MEAV that result from cleansing are a problem in constructing a consistent measure of capital cost. Without adjustment, these changes do not reflect actual movements in the asset base in the year in which they occur. They could therefore affect the productivity estimates from Törnqvist modelling without reflecting actual operational changes.

The first-order concern for the Törnqvist analysis is to avoid level changes in MEAV during the sample period that do not reflect actual operational changes. Such changes would impact the estimated productivity trend. We therefore engaged with the DNOs to understand whether the cleansing changes were likely to be corrections that would also have been applicable for the whole period, i.e. since the beginning of DPCR5 in 2010/11.

Based on discussions with the DNOs, we understand that in practice the cleansing changes fall into two categories:

[224] Ofgem (28 November), RIIO-ED1: Draft determinations for the slow-track electricity distribution companies: Business plan expenditure assessment – Final Decision, Table 12.2

- Smaller year-on-year revisions, seen in most years of the sample period. DNOs indicated that these will often reflect assets that are originally reported a year early or late, but that do reflect changes to their asset bases during the sample periods; and
- Distinct rounds of revising the asset registers, resulting in larger cleansing changes. DNOs indicated that these changes were more likely to be corrections that would have been applicable since the start of the sample period.

The modelling therefore does not make any adjustments based on the first category of revisions, but does address the larger data cleansing exercises carried out by some DNOs. In discussions, the DNOs concerned identified the cleansing changes they considered would fall into the second category:

- Two DNOs identified changes to specific asset categories in a specific year as being driven by a data revision exercise;
- Two DNOs identified all changes to the asset register in a specific year as being driven by a data revision exercise; and
- Two DNOs identified all changes to the asset register in two specific years as being driven by a data revision exercise.

Cleansing changes for the other eight DNOs were smaller as a share of MEAV, and no adjustments were made for these DNOs. We therefore adjusted the data based on the specific changes identified by the six affected DNOs. In each case we applied the identified cleansing changes from the start of the sample in 2010/11 to create a consistent MEAV time series. The overall impact of the adjustments is an increase in the estimated TFP growth rate.

A.1.3. Output Data

Data on six of the seven output variables is sourced from the Cost and Volumes Table M14 as provided by the DNOs. In the case of two DNOs, a round of asset register revisions as identified in Appendix A.1.2 coincided with a reduction in the driver network length larger than the movements for other years.[225] To avoid having an inconsistent measure of network length as a consequence of the data cleansing, we agreed with the DNO to adjust the earlier years of data. We did this by subtracting the difference between the first year after the cleansing and the final year before the cleansing from all years prior to the cleansing round.

The modelling sources the data on the installed capacity of embedded generation from each company's Embedded Capacity Register (ECR). The ECR contains data on generators connected to each DNOs network. This includes the installed capacity and the date of connection. The modelling measures DG for a fiscal year ending in a given year as the installed generation capacity (MVA) connected on or before 31 of March of that year.

The ECR data for some DNOs is incomplete, which will result in some measurement error in the DG output variable. There may also be measurement error where embedded generators have disconnected during the sample period. The ECR data available for two DNOs was not sufficiently complete to be included in this study. The two affected DNOs are therefore excluded from the data set for all models containing DG as an output variable.

225 For one of the DNOs the reduction was 10 per cent in a single year.

A.2. Regression Modelling

Table A.2 shows the full regression tables for the five model specifications used in Section 4. The dependent variable across all regression specifications is the logarithm of total costs. The table shows significance levels and p-values calculated using heteroskedasticity and cluster robust errors.

Significance is one of the statistical criteria used to select model specifications. Model 5 contains some statistically insignificant coefficients as this model specification includes DNO dummies that reduce its statistical power. Model 3 also contains one statistically insignificant coefficient. In both cases all output variables included are statistically significant in other model specifications. All other coefficients on output variables are significant at the 5 per cent level. We include the model specifications that contain some statistically insignificant coefficients in order to have a diversity of model specifications, which is one the criteria set out in Section 4.5. Uncertainty around coefficient estimates may reduce the accuracy of the resulting output weights.

We also considered model specifications containing time trends. These performed poorly against the statistical criteria that Section 4.4 sets out. For example, a time trend added to the five model specifications in Table A.2 is not significant at the five per cent level in four of the models. The time trend would be statistically significant in Model 5, but when included the coefficient on both output variables are of the wrong sign.

Table A.2: Regression Results for Five Model Specifications

	Model 1	Model 2	Model 3	Model 4	Model 5
customers_log	0.432***		0.762***		0.066
	{0.000}		{0.000}		{0.876}
length_log	0.486***			1.015***	
	{0.000}			{0.000}	
peak_demand_log		0.662***			
		{0.000}			
DG_log		0.123**	0.040		
		{0.030}	{0.461}		
CI_log				-0.212**	-0.023
				{0.035}	{0.416}
DNO1					-0.267
					{0.123}
DNO2					0.033**
					{0.044}
DNO3					-0.484
					{0.320}
DNO4					0.298**
					{0.019}
DNO5					-0.188**
					{0.018}
DNO6					-0.196
					{0.329}
DNO7					-0.298***
					{0.000}
DNO8					-0.131***
					{0.000}
DNO9					0.332*
					{0.083}
DNO10					0.069
					{0.153}
DNO11					-0.045
					{0.117}
DNO12					-0.669*
					{0.051}
DNO13					-0.345*
					{0.057}
_cons	-5.378***	-0.122	-5.168***	-4.058***	5.455
	{0.000}	{0.870}	{0.004}	{0.006}	{0.393}
N	140	120	120	140	140

*Notes: Asterisks denote significance levels. * 10% ** 5% *** 1%. {} denote p-values.*
Source: NERA analysis of DNO data.

A.3. Calculating Törnqvist Indices

This subsection provides a step-by-step mathematical description of the calculation of Törnqvist indices for output from the regression coefficients. The section's notation uses the subscripts "k" to refer to outputs, "i" to refer to DNOs, and "t" to refer to years. Each observation is a combination of a DNO i and a year t. It uses Model 1, which contains the output variables customer numbers and network length, as an example.

The first step is calculating the influence of each output variable on costs for each observation across DNOs i and years t. The modelling calculates the cost contribution of each output variable k as the estimated coefficient for the variable ($\hat{\beta}_k$) multiplied by the logarithm of that variable.[226] In the case of CI and CML the modelling uses the absolute value of the coefficient as the coefficients on these variables are negative.

$$Cost\ Contribution_{k,i,t} = \hat{\beta}_k \times \ln(Output_{k,i,t})$$

The share of the modelled costs for each observation is the cost contribution of each output variable divided by the sum of the cost contributions of all output variables in that model specification. In the example of Model 1, the cost share of customer numbers is:

$$Share_{Cust,i,t} = \frac{Cost\ Contribution_{Cust,i,t}}{Cost\ Contribution_{Cust,i,t} + Cost\ Contribution_{Length,i,t}}$$

The cost shares used to weight outputs in the Törnqvist index can vary across years t, but are the same for all DNOs i. The modelling therefore calculates a weighted average cost share for each output in each year. Within each year, each observation is weighted by the predicted cost of that observation as estimated by the regression analysis:[227]

$$\ln\widehat{(Cost)}_{\iota,t} = \hat{\alpha} + \hat{\beta}_{Cust} \times \ln(Customers_{i,t}) + \hat{\beta}_{Lengt}\ \ \times \ln(Length_{i,t})$$

Which yields the weight attached to each observation i,t within all the observations for year t:

$$Weight_{i,t} = \frac{\ln\widehat{(Cost)}_{\iota,t}}{\sum_i \ln\widehat{(Cost)}_{\iota,t}}$$

The weighted average cost share for customer numbers in Model 1 is then:

$$Share_{Cust,t} = \sum_i Weight_{i,t} \times Share_{Cust,i,t}$$

The Törnqvist index is a chained index calculated based on the growth in each output from one year to the next. It therefore uses a two-year average of the share when weighting each output. In the case of customer numbers from Model 1:

$$Share_{Cust,t}^{Two\ year} = \frac{1}{2} \times Share_{Cust,t} + \frac{1}{2} \times Share_{Cust,t-1}$$

226 This is the contribution of that output variable to total costs as measured in logarithms.

227 Note that it is the predicted logarithm of cost, as opposed to the logarithm of predicted cost.

The Törnqvist index of outputs is 1 in the base year 2010/11. The rate of growth from each year to the next is then calculated as the weighted combination of the growth in each of the constituent outputs. The equation below shows the construction of the Törnqvist output index for Model 1.

$$\frac{Törnqvist\ Output\ Index_t}{Törnqvist\ Output\ Index_{t-1}} = \left(\frac{Customers_t}{Customers_{t-1}}\right)^{Share_{Cust,t}^{Two\ year}} \times \left(\frac{Length_t}{Length_{t-1}}\right)^{Share_{Leng\ ,t}^{Two\ year}}$$

The total factor productivity index then results from dividing the Törnqvist output index by an index of total costs:

$$Productivity\ Index_t = \frac{Törnqvist\ Output\ Index_t}{Cost\ Index_t}$$

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