Topics in efficiency benchmarking of energy networks: Estimating capital costs

Prepared for
The Netherlands Authority for Consumers and Markets

15 December 2017

Economic Insights Pty Ltd
Ph +61 2 6496 4005 Mobile +61 438 299 811
WEB www.economicinsights.com.au
ABN 52 060 723 631

CONTENTS

EXECUTIVE SUMMARY

This paper discusses various issues in calculating standardised capital costs when undertaking efficiency benchmarking of energy networks. The focus is on calculating capital costs for use in the application of data envelopment analysis (DEA). Although many approaches are discussed in the report, it needs to be recognised that feasibility and resource limitations will influence the most ideal or optimal approach that can be implemented in practice.

Context and relevant economic principles

Regulatory context and efficiency studies

In a regulatory context, the focus on capital costs is typically concerned with establishing a return on capital and a return of capital (depreciation) to form a total capital charge (payment) that will enable the recovery of relevant capital costs over time. This focus is important for ensuring that there are sufficient incentives to support economically efficient investment. In some jurisdictions the principle is referred to as the net present value (NPV)=0 principle.

There is a myriad of capital charge profiles that can satisfy the NPV=0 principle and regulators in different jurisdictions may differ substantially in the profile of the capital charges that they approve.

The point of noting these aspects of regulatory decisions is that the asset values and depreciation and return on capital parameters are not necessarily suitable when undertaking benchmarking where it is important to 'standardise' some key parameters given the typical focus is on assessing some measure of efficiency and, hence, like needs to be compared with like. This is particularly the case where only one overall input is included in the analysis.

However, if a benchmarking study does not use the same cost concepts as the regulator of a utility, the regulator can still use the efficiency scores derived from the benchmarking study to estimate efficient costs for the utility using its own capital cost parameters.

The rental rate or price of capital services and capital inputs

The standard expression of the cost of capital services defines a user cost analogous to the price of other inputs but recognising that capitals services are based on a stock of capital. The user cost of a unit of capital services is defined as is $cK = q(n + \delta - \Delta q/q)K$. This expression highlights the distinction between the price of capital services c which depends on the price of the capital or investment good q, the required investment return n, physical depreciation δ (in terms of the reduction in capital services for a given unit of capital) and capital gains for the asset $\Delta q/q$, and the quantity (volume) of capital services K. The standardisation of capital costs typically entails the standardisation of the term $(n + \delta - \Delta q/q)K$.

Standardisation of capital costs

The case for standardisation across jurisdictions

The main reason for standardisation is that for an efficiency study the focus should be on comparing like with like. Without standardisation of key parameters it is difficult to measure the distance from the production or cost frontier and indicate what the true efficiency shortfalls are.

However, we recognise that standardisation does not take account of the possibility that input choices may be affected by different capital cost parameters and that standardisation could lead to some misleading cost efficiency scores in a DEA study. The issue is essentially an empirical one and could only be fully resolved by comparison of results using standardised parameters and country specific regulated returns. However, our a priori assessment is that there is likely to be relatively limited scope for TSOs to change their input mixes in response to different relative prices for operating and capital expenditure. So we consider that standardisation is a reasonable default approach.

The issue of whether different cost of capital parameters would have led to different decisions about the mix of capital and operating inputs could be examined as a separate sensitivity analysis. If an empirical study was done comparing the results from a standardised versus a non-standardised approach and found the relative rankings to be the same then this would provide support for the use of standardisation in the future, thereby simplifying the benchmarking process.

Approaches to standardisation of the capital input

The two main approaches to the standardisation of capital costs are: (i) a real constant user cost of capital services in combination with a measure of the capital stock (real user cost approach); and (ii) a real constant annuity based on investment stream data (annuity approach). They are consistent from an economic perspective and effectively require the same data set for efficiency analysis.

The main difference is that the annuity approach ensures a constant real capital charge and in doing so endogenises the depreciation rate. The user cost approach may be more regularly observed in regulatory decisions but, for efficiency analysis, both approaches require standardisation of the rate of return, investment or asset values and the form of depreciation and compliance with the NPV=0 condition.

The different approaches to depreciation are not considered likely to have an impact on investment decisions. The annuity approach may be easier to implement when historical investment data are missing and starting asset values are not considered likely to reliably reflect depreciated historic costs.

Two alternatives to these approaches involve focusing only on a measure of the real capital stock K. One approach focuses on real investment or capital stock data in monetary terms and the other approach uses physical measures of the capital stock. These approaches are used in productivity index studies to calculate capital productivity indexes. They may be useful for undertaking sensitivity analysis.

Measuring depreciation

There are many ways to specify depreciation to ensure that the NPV=0 principle applies. The most common form of depreciation used in regulatory decisions is straight-line depreciation which entails the deduction of a constant proportion of an asset, usually reflecting the inverse of the life of the asset when the investment first occurs. Other forms of depreciation effectively relate to more front-loading or back-loading of depreciation charges. One-hoss shay depreciation defers all depreciation to near the end of the life of the asset. A constant real annuity usually means less depreciation in the early years of the life of the asset than occurs for straight line depreciation.

The form of depreciation chosen in regulatory decisions depends on the objectives of the regulator. The form of depreciation chosen in an efficiency study will often be influenced by data availability. The annuity approach may have advantages over the user cost approach if the data available varies across firms and/or is incomplete for some firms.

Measuring the rate of return

Like variability in depreciation rates, variability in rates of return, across jurisdictions and over time, could make it difficult to identify efficiency differences for capital inputs. It would also be unnecessarily complex. Using a standardised return on capital and standardised return of capital across jurisdictions allows like-for-like treatment of real capital inputs.

The issue of whether the quantity of investment would have changed if the rate of return was materially different and impacted on conclusions about efficiency could be examined separately where relevant and used to qualify the findings of the first stage efficiency analysis. However, where regulatory institutions have broadly similar regulatory arrangements and levels of market development we expect there would be limited impact on investment decisions.

The rate of return could be established by choosing parameters in a WACC measure based on recent average regulated WACCs in major European countries with similar regulatory institutions and a broadly similar level of market development. Relevant real returns are not expected to change to such an extent over time such that cost comparisons across jurisdictions would be materially affected and so the choice of a base year is not considered critical.

Measuring asset values

In typical regulatory determinations capital charges are calculated based on applying an allowed rate of return to an approved regulatory asset base (RAB) and part of the allowed capital expenditure for that year, and specifying an allowed amount of depreciation based on assumed asset lives.

The existing RAB values across European jurisdictions can differ substantially in terms of how they were established and the extent to which they represent actual depreciated historical expenditures or a replacement value or a value based on some other benchmark or regulatory process. Some NRAs use historic cost, some use indexed historic cost and some use other methods to revalue assets, including a mix of historical and re-evaluated assets and regulatory determined allowances. The approaches to including assets under construction also vary.

There is a need to establish separate consistent measurement of capital inputs, to that used in regulatory approaches, when undertaking benchmarking studies.

The main approaches for calculating opening capital costs are summarised below.

Asset valuation approaches

The depreciated historic cost (DHC) approach is simply based on historic actual expenditure less accumulated depreciation recovered in charges to date. The DHC approach can also be modified to index the asset base when it is rolled forward over time. However, if this is done then a real WACC should be applied to avoid double counting of inflation.

The main advantage of the DHC approach to valuation is the degree of certainty that it creates for the regulated entity that it will be able to recover the value of its actual investment (meeting the NPV=0 condition).

A potential problem with the DHC approach is that historical information may not reliably reflect actual expenditure and the depreciation that has been recovered in capital charges.

The depreciated optimised replacement cost (DORC) concept is based on using replacement (current cost) values for the assets but with adjustments to reflect optimisation of the network, including removing unused assets, reducing the capacity of under-used assets, using modern equivalent assets in terms of their service capacity, and with deductions for depreciation recovered to date.

The main problem with the DORC approach, when used to re-determine the value of assets from period-to-period, is that it is not consistent with adhering to the NPV=0 principle. The use of replacement cost to value assets can lead to windfall gains and losses based on the value of a network that would never be built. In addition, the approach requires considerable judgement and discretion in establishing optimised values. However, the DORC approach may be helpful in establishing an initial value when the historic data are unavailable or unreliable.

Recent sales values can be used to establish a base value and a DHC approach can be applied to that base value going forward. The main problems with this approach are that the privatised entity often has substantial non-regulated business and the sale value can reflect expectations of earning above normal profits, particularly where allowed rates of return are expected to exceed the cost of capital.

An alternative to using direct measures of capital costs, based on applying rates of return and rates of depreciation to a consistent measure of the RAB, is to establish the real value of long term investment streams and annuities to recover the cost of the investment streams. This approach is closely related to the DHC approach, with both requiring consistent data. There should not be much difference in terms of measuring the capital input. This approach may also be easier to implement.

Estimating historical investment series

To achieve standardisation of asset values it is likely to be necessary to re-construct asset bases using standardised depreciation and ideally using price indexes that reflect capital goods inflation. This may require historical data spanning a long period. Where investment or asset value data are not available, one approach is to estimate a capital to output or standardised investment to output ratio and use the ratio to impute relevant investment or capital stock data for an earlier period.

A generic 'capex break methodology'[1] has been developed and applied for European TSO benchmarking that estimates a ratio of standardised capital expenditure to a measure of standardised grid size. This approach has the advantage of being objective and transparent and to improve it further would require detailed study of whether the measure of the standardised grid variable could be improved.

The 'capex break methodology' has also been shown to be feasible. However, it has the disadvantage of assuming a constant ratio of standardised capital expenditure to a measure of standardised grid size.

Another approach would be to develop backcast projections based on observing trends and patterns in investment or undertake more involved econometrics examining the impact of investment drivers to establish missing values. Berlemann and Wesselhoft provide a useful survey of the literature on estimating initial capital stock values or early investment data based on three approaches used for major sectors and at the national level.[2] Different modelling approaches using different drivers are used to form estimates of the missing investment data. They present a fourth approach that combines various aspects of other approaches to try to overcome various disadvantages with those approaches. They then estimate the capital stock at an aggregate level using their approach and the first three approaches for 103 countries.

Their methodology entails using the fitted results from a regression of a long time-series on investment on a time trend and using this information to establish an initial investment value and initial estimate of the capital stock. They found the four approaches they used to converge quite quickly in the course of time but preferred their approach as it was designed to address weaknesses of the other methods.

The Berlemann and Wesselhoft methodology may be resource intensive but does not assume a constant capital output ratio and appears promising.

It would be of interest to compare the results using the capex break methodology with an approach based on the Berlemann and Wesselhoft methodology.

Rolling forward the asset base

Once an initial asset base has been properly established then it is quite straight forward to roll it forward in a way that satisfies the NPV=0 principle. If the asset base is indexed then it is rolled forward after deducting depreciation and adding capital expenditure in the prior year and then indexing using a suitable price index.

As noted, there may be a need for a different indexing factor when undertaking efficiency analysis compared with what is used in regulatory decisions.

[1] See Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, pp. 63-64 and Frontier Economics, Sumicsid and Consentec (2013), Method Note 1: Capital break methodology – Opening Balance Adjustments, e3GRID2012 PROJECT, 28 March/ver 1.5.

[2] Berlemann, M., and J. Wesselhoft (2014), Estimating Aggregate Capital Stocks Using the Perpetual Inventory Method – A Survey of Previous Implementations and New Empirical Evidence for 103 Countries, Review of Economics, 65, 1-34.

The other main decision relates to whether to roll the asset base forward using the forecast depreciation from a regulatory period or actual depreciation. Either approach can be made to be consistent with the NPV=0 principle. The use of forecast depreciation may be preferable in terms of balancing incentives to provide accurate forecasts and achieve capital efficiency savings, depending on the regulatory arrangements. Adjustments for financing benefits and costs where actual capital expenditure differs from forecast capital expenditure are also easier if forecast depreciation is used.

Asset disposals should be treated as disinvestment and used assets acquired through mergers or other means and upgrades should be valued at acquisition prices and added to the regulatory asset base, with appropriate adjustments for remaining asset lives and capital charges.

Converting to common monetary units

Adjusting the RAB or investment streams for inflation

The RAB does not need to be adjusted for inflation when it is rolled over if a nominal rate of return is applied to the DHC value of the RAB. If the RAB is indexed for inflation for regulatory purposes a real rate of return should in effect be applied to ensure there is no double counting of inflation. However, there are also complications if the RAB is indexed in choosing an appropriate deflator for indexing purposes.

If one takes an investors' perspective when indexing the asset base or defining a real rate of return, the relevant inflation index is the consumer price index as this is the measure that reflects general purchasing power and is relevant for incorporation in the opportunity cost measure for an investment return.

But for benchmarking purposes one needs to reflect an asset value in terms of its real purchasing power in relation to capital quantities. That means it needs to be based on a measure of historic costs and, if converted to real magnitudes, it needs to be indexed by the most relevant capital or investment goods deflator.

If there is no RAB and an investment stream is used it should be first formulated in nominal terms expressing what was spent or is projected to be spent. It can then be converted to real terms using a relevant capital goods deflator.

The discount rate should be first formulated in nominal terms from the investors' perspective (which means that it will contain an implicit component to compensate for inflation, typically measured by the consumer price index) and then an adjustment should be made for nominal capital gains (or losses) for the particular asset class.

Relevant deflators

Ideally the deflators for cost categories should represent the specific costs in the relevant categories and not other costs. Thus, for capital expenditure for energy network businesses the most relevant deflator would be a deflator that represented construction and equipment costs while for operating expenditure the deflator would represent labour plus relevant intermediate goods and services costs. However, producer price indices are not generally available for goods or sectors that would be representative of construction costs or equipment investment for energy network businesses and relevant sector-specific indexes only exist for a handful of countries. Under these circumstances using country–specific CPIs may be the best choice available.

Adjusting for prices across countries

Adjusting for prices across countries can be done by using market exchange rates or purchasing power parities (PPPs). PPPs are preferable because market exchange rates can lead to misleading comparisons of real magnitudes when national price levels differ substantially across countries. PPPs also adjust for spatial differences as well as currency differences.

To ensure the most comparable comparison of quantities the PPPs should relate to the expenditure category that is closest to the capital expenditure of energy network businesses. We consider that the construction investment category, if available, is likely to be the most suitable PPP for converting capital costs to a uniform and common price level for energy network businesses. Where sector specific PPPs are not available the GDP PPP could be used. For operating costs, the GDP PPP is likely to be the most appropriate and readily available.

Distinguishing between operating and capital costs

The use of a single total cost input can limit the options available for measuring capital inputs (since the price and quantity of those inputs are necessarily combined). In addition, if more than one input is included then results for allocative efficiency can be separated from the results for overall cost efficiency. This will provide information on how close a particular firm is to adopting an input mix that minimises its costs, given its level of technical efficiency.

Potential for using total operating and capital expenditure in benchmarking

Rather than focussing on capital costs and total costs, benchmarking could focus on capital expenditure and total expenditure. This approach is used by Ofgem in the United Kingdom and has some advantages, in a regulatory context, when the main flexibility in improving performance, in relation to the capital input, relates to capital expenditure rather than the sunk capital base. Another advantage is that the data requirements on the capital side are considerably less demanding. However, a problem with using capital expenditure instead of a measure of real capital costs or the quantity of capital is that it does not reflect the economic concepts in the cost or production function and does not take account of the need for at times lumpy expenditure profiles. This approach would require a separate study to assess its potential. An outline of key aspects is provided in Annex 1.

1 INTRODUCTION

This paper discusses various issues in calculating standardised capital costs when undertaking efficiency benchmarking of energy networks. The focus is on calculating capital costs for use in the application of data envelopment analysis (DEA).

The aim of the paper is to address a number of important practical issues in estimating the capital-related costs of electricity and gas transmission businesses that arise in a multilateral benchmarking context. These issues arise: in part due to limitations in the availability and reliability of data for the businesses included in the sample; and in part because the businesses being benchmarked are generally in different countries and different regulatory jurisdictions, which raises certain issues relating to consistency and standardisation of capital cost data to ensure like-for-like comparisons.

The term ‘standardised capex’ referred to in the terms of reference is understood to refer to the economic cost of capital employed, as distinct from actual capital expenditure. We interpret *standardised capex*, as referred to in the terms of reference as comprising: (i) depreciation plus (ii) the weighted average cost of capital (WACC) multiplied by the Regulatory Asset Base (RAB) including a provision for capital expenditure each year. We also note that, in several studies, ‘standardised capex’ is included with operating expenditure (opex) to form total expenditure (totex).

In contrast, we note that in the United Kingdom Ofgem’s benchmarking[3] focuses on totex defined as the sum of operating expenditure and capital expenditure rather than capital costs (comprising depreciation and a return of capital). In addition to considering various issues in relation to ‘standardised capex’, the potential for focussing on totex as defined in the United Kingdom will be discussed.

The paper addresses the following topics:

- Context and relevant economic principles
- Standardisation of capital costs
- Measuring depreciation
- Measuring the rate of return
- Measuring asset values
- Converting to common monetary units
- Distinguishing between operating and capital costs, and
- Potential for using total operating and capital expenditure in benchmarking.

[3] Ofgem, Strategy decisions for the RIIO-ED1 electricity distribution price control: Tools for cost assessment, 4 March 2013, p. 10. Ofgem, RIIO-ED1: Final determinations for the slow-track electricity distribution companies—Business plan expenditure assessment, 28 November 2014, pp. 28-30.

2 CONTEXT AND RELEVANT ECONOMIC PRINCIPLES

2.1 Recent studies of European energy network businesses

Several recent benchmarking studies of European energy transmission businesses were reviewed to help identify key issues. A brief summary of key aspects of these studies is presented below:

- Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June.
    - Data for 21 (after excluding one outlier) European electricity TSOs were analysed using DEA and SFA. Totex (return on capital plus depreciation plus operating expenditure), measured in real terms, was the measure of cost. Three output measures were used – a normalised grid (a weighted sum of all activity-relevant pipeline, regulator and compressor assets including connection points, with adjustments for geographical complexities) as a proxy for the complexity of the operating environment; a measure of peak capacity; and the total number of connections.
    - The capital cost data were standardised. Capex was based on applying a real annuity factor to real (undepreciated) investment streams (with the full span of data from 1970 to 2014), with standardised asset lives. The real annuity ensures the recovery of a return on and of capital over the specified life of the asset. A number of adjustments were made to reflect upgrading of assets and to deduct various capitalised costs. Nominal investment streams were converted to real investment streams using the CPI and average exchange rates. A standard real rate of return of 3 per cent was used to calculate the rate of return on capital.
    - Sensitivity analysis was undertaken using producer price indexes (where available and CPI where not available) and purchasing power parity exchange rates. Sensitivity analysis was also undertaken using alternative definitions of the normalised grid to take account of missing data and different interest rates. There was minimal impact in all cases.
- Frontier Economics and Consentec (2016) Gas TSO efficiency analysis for the Dutch transmission system operator: A report prepared for ACM, January.
    - Data from 13 gas TSOs provided by the German NRA (Bundesnetzagentur (BNetzA)) were analysed using DEA. Totex (opex plus capital costs) measured in real terms was the measure of costs Three types of output measures were confirmed as final candidates – connection points (granularity); capacity provision; and measures of supply area (network expansion).
    - The capital cost data were standardised. A standard rate of return of 5.8 per cent was used and applied to indexed historic costs, using a perpetual inventory methodology for the asset base. A number of adjustments were made to include relevant capital costs (e.g. non-controllable capital costs) that

had been excluded from the data provided by BNetzA. The RAB did not include assets under construction and intangible assets and some other cost adjustments were made to standardise approaches. Undepreciated investment data were used to establish asset values. Standardised asset lives and depreciation were used.

- Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July.
  - Data for 21 European electricity TSOs were analysed using DEA. Totex (return on capital plus depreciation plus operating expenditure) measured in real terms was the measure of cost. Three output measures were used – a normalised grid as a proxy for the complexity of the operating environment; population density; and the value of weighted angular towers as a further measure of the complexity of the operating environment.
  - The capital cost data were standardised in a similar manner to Sumicsid and Swiss Economics (2016). Capex was based on applying a real annuity factor to real (undepreciated) investment streams (with the full span of data from 1965 to 2011), with standardised asset lives. Nominal investment streams were converted to real investment streams using the CPI and average exchange rates. A standard real rate of return of 4.36 per cent was used.
  - For those businesses where there was incomplete investment data a 'capex break' methodology was applied to estimate missing investment values. This methodology assumes that the average ratio between investments and the capex grid size, defined as the physical assets multiplied by their cost weights, for the period when investment data are available will apply for the period when investment data are not available (p. 63).[4]
- Sumicsid (2009), International Benchmarking of Electricity Transmission System Operators e3Grid Project, Final Report, P. Agrell and P. Bogetoft, 3 September.
  - Data for 22 European electricity TSOs were used to test different benchmarking methods. Totex (return on capital plus depreciation plus operating expenditure) measured in real terms was preferred as a measure of cost. A normalised grid, density and renewable power including hydro were the cost drivers.
  - The capital cost data were standardised in a similar manner to Sumicsid and Swiss Economics (2016). Capex was based on applying a real annuity factor to real (undepreciated) investment streams (with the full span of data from 1964/1965 to 2006), with standardised asset lives. Nominal investment streams were converted to real investment streams using the CPI and average

4 See Frontier, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, pp. 63-64 and Frontier Economics, Sumicsid and Consentec (2013), Method Note 1: Capital break methodology – Opening Balance Adjustments, e3GRID2012 PROJECT, 28 March/ver 1.5.

exchange rates. A standard real rate of return of 4.86 per cent was used. There was no discussion of exchange rate adjustments.

- Jamasb,T., D. Newbery, M. Pollitt, T. Triebs (2007) 'International Benchmarking and Regulation of European Gas Transmission Utilities: Final Report' (Prepared for the Council of European Energy Regulators (CEER) – Task Force on Benchmarking of Transmission Tariffs).
  - Data for 40 US and four European gas TSOs (328 observations) were used to examine different benchmarking methods including DEA. The input variable in all of the models was a measure of costs. Opex, Totex 1 (opex plus depreciation) and Totex 2 (opex, plus depreciation plus return on capital) and Revenue were tested as cost measures. Cost drivers included throughput and various capacity measures.
  - All cost measures were adjusted for inflation using consumer price indices and 2004 purchasing power parities. A return on capital of 7 per cent was applied. Depreciation rates were not standardised and the age of assets was not accounted for. The inflation adjustment for assets only covers the period of reporting, not the period from the date of purchase.
  - The report recommended that standardisation of data be a priority area for regulators and also concluded that revenue is highly correlated with cost measures and produces very similar efficiency scores across firms.

2.2 Regulatory context

In a regulatory context, the focus on capital costs is typically concerned with establishing a return on capital and a return of capital (depreciation) to form a total capital charge (payment) that will enable the recovery of relevant capital costs over time. This focus is important for ensuring that there are sufficient incentives to support economically efficient investment. In some jurisdictions the principle is referred to as the NPV=0 principle (see 2.3 below) or the financial capital maintenance principle, meaning that capital charges need to be defined so that an investor can expect to earn their required return on capital and also recover the initial cost of the investment but not earn above normal risk-adjusted returns.

Although many regulators are concerned to ensure the NPV=0 principle is applied, regulatory arrangements have evolved where the starting value of assets may not be a good reflection of an asset value that reflects historical expenditures less depreciation recovered to date. This issue is considered in more detail in Section 6.

However, assuming the starting asset value is considered appropriate, there is a myriad of capital charge profiles that can satisfy the NPV=0 principle and regulators in different jurisdictions may differ substantially in the profile of the capital charges that they approve. For, example, the standard starting point for depreciation is straight line depreciation where an equal proportion of an original investment is recovered over the life of the asset. But straight-line depreciation is an accounting convention that does not necessarily correspond to physical depreciation. Straight line depreciation also does not necessarily correspond to economic depreciation which, in a well-functioning competitive market, should reflect the change in the market value of the assets in question.

In a regulatory context and from a financial perspective, depreciation allowances can be front loaded (accelerated) or back loaded to achieve other policy objectives (addressing risk, affordability, allowing for growth) while still being consistent with the NPV=0 principle.[5]

In some jurisdictions accelerated depreciation is approved for regulated assets such that the full value of the asset is recovered well before its useful physical life. Straight line depreciation may still be used but over a shorter time span then a physical useful life. At the other extreme, minimal depreciation may be reflected in lower allowed capital charges for a time, with a commitment to increase depreciation later, to reflect expected growth in demand and a more efficient and equitable recovery of capital costs in the future.

Given most energy network assets are sunk and assuming entry is not feasible, allowed depreciation, in a regulatory context, does not have to correspond to either economic depreciation of assets in a competitive market or to physical depreciation. It is important to recognise that regulators are typically not focussed on setting depreciation to correspond closely to the physical capacity of the assets but rather to ensure recovery of the cost of the investment over a timeframe that takes account of a number of considerations. As indicated, the key profitability condition that regulators typically have regard to is the NPV=0 condition (or an approximation).

Different accounting conventions for measuring depreciation also do not necessarily correspond to the physical capacity of assets and are not designed for benchmarking purposes.

European regulatory authorities use various approaches for estimating asset values and depreciation in their regulatory decisions for allowed revenues and prices. Straight line depreciation is common but in some cases it is applied to the replacement (current) value of a network and in some cases to historic book values. In addition, in some cases it is applied at an aggregate level and in some cases for individual assets.[6]

For the return on capital, regulators in different jurisdictions may also apply different approaches and adopt different parameters reflecting different economic and regulatory circumstances and judgements about appropriate inputs. Although most European regulators use the weighted average cost of capital (WACC) and the capital asset pricing model (CAPM) for determining the cost of equity, some regulators are constrained by legal requirements and parameters and timeframes can vary considerably.[7] There is a wide divergence in the WACCs determined by regulatory authorities in different countries.[8]

---

[5] This is an application of the invariance proposition of Schmalensee, Richard, 1989. "An Expository Note on Depreciation and Profitability under Rate-of-Return Regulation," Journal of Regulatory Economics, Springer, vol. 1(3), pages 293-98, September.

[6] Council of European Energy Regulators (CEER) (2017), CEER Report on Investment Conditions in European Countries, Ref: C16-IRB-29-03, 24 January, pp. 146-154.

[7] Council of European Energy Regulators (CEER) (2017), CEER Report on Investment Conditions in European Countries, Ref: C16-IRB-29-03, 24 January, pp. 23-100.

[8] CEER 2017, pp. 23-100 and Ernst & Young (2013) 'Mapping power and utilities regulation in Europe'.

The point of noting these aspects of regulatory decisions is that the different asset values and depreciation and return on capital parameters used by each regulator are not necessarily suitable for undertaking benchmarking. Rather, it is important to 'standardise' key parameters given the typical focus is on assessing efficiency and, hence, like needs to be compared with like. This is particularly the case where only one overall input is included in the analysis and allocative efficiency cannot be separately identified.

However, if a benchmarking study does not use the same cost concepts as the regulator of a given utility, the regulator can still use the efficiency scores derived from the benchmarking study to estimate efficient costs for the utility using its own capital cost parameters. Consider the example of a utility with costs of 70 million using the regulator's capital cost parameters but 50 million using standardised capital cost parameters used in the benchmarking study. If the benchmarking study finds the utility to be 80 per cent efficient then its efficient costs will be 56 million using the regulator's capital cost parameters (= 0.8 x 70m). This could alternatively be derived by adjusting the efficient cost estimate using the benchmarking study's capital cost parameters for the difference between the benchmarking study's and the regulator's cost measures as follows: (0.8 x 50m) x (70m/50m) = 56 million.

In practice the regulator may choose to adjust the benchmarking study's cost efficiency score when setting the cost target for its utility to take account of additional circumstances.

2.3 The NPV=0 condition and implications for the profile of capital charges

The rate of depreciation and the allowed rate of return on capital in effect together constitute the unit price or (implicit) rental rate of capital services (also referred to as the user cost or service price of a unit of capital). When applied to the value of capital (the starting RAB for a period and part of the capital expenditure for the period) the result is the capital cost or capital charge for the services of the asset in a period.

The return on capital and the return of capital (allowed depreciation) can be combined into a single capital charge in the form of an annuity and the annuity can be indexed to increase or decrease over time as long as starting capital charges are adjusted to ensure the NPV=0 condition is satisfied. The annuity in effect endogenises the rate of depreciation which will depend on the rate of return and whether the annuity is indexed. This is shown in section 3.2.

2.4 The rental rate or price of capital services and capital inputs

It is helpful to consider the standard definition for the rental rate or user cost of a unit of capital services using Jorgenson's notation from an early paper where he derived the standard definition in explaining the neo-classical theory of investment (or investment in perfectly competitive markets):[9]

(1) $c = q(n + \delta - \Delta q/q)$

where:

---

[9] This formulation was originally due to Jorgenson and still forms the basis for the economic interpretation of the rental rate or service price or user cost of a unit of capital. See, Jorgenson, D.W. (1967) The Theory of Investment Behaviour, National Bureau of Economic Research in R. Ferber, ed., Determinants of Investment Behavior.

- c = is the nominal rental value of a unit of capital services;
- q = the nominal price of a unit of capital services;
- n = the nominal discount rate (that is, the opportunity cost-of-capital or WACC);
- δ = reduction in the flow of the capital services input for a unit of capital services;
- Δq/q = the proportional change in the nominal price of a unit of capital services; and
- all these variables are functions of time, but the time subscripts are removed for simplicity.

If the proportional change in the nominal price of a unit of investment is assumed to be equal to the inflation rate embedded in the discount rate, then r – Δq/q approximates a real discount rate expressed in terms of investment goods. However, note that the inflation rate embedded in the discount rate should be the inflation rate that is most relevant from an investors' perspective i.e. to maintain their general purchasing power. This is discussed further below in Section 6. Alternatively the term δ – Δq/q can be interpreted as the economic depreciation of a unit of the investment.

This standard expression was derived as part of the neoclassical theory of investment and holds in a perfectly competitive market where incremental adjustments in investment can be made and there are no sunk costs and there are competitive markets for used assets. However, the formula is also widely used in markets where there are sunk costs and in regulatory contexts. The formula forms the basis for the concept of the capital charge comprising the return on capital and the return of capital in a regulatory context and is provided here to help clarify the interpretation of quantity and price variables.

The quantity of capital services is typically assumed to be proportional to a measure of the capital stock, defined as K. The user cost is defined as $cK = q(n + \delta - \Delta q/q)K$. This expression highlights the distinction between the price of capital services c which depends on the price of the capital or investment good, the required investment return, physical depreciation (in terms of the reduction in capital services for a given unit of capital) and capital gains for the asset, and the quantity (volume) of capital services K. The analogous expression for the cost of labour would be the cost of labour times the quantity of labour r and, for opex, a price deflator for opex times the quantity of opex inputs.

Several of the DEA studies, that we have considered, have standardised $(n + \delta - \Delta q/q)K$. The approach used by Sumicsid and Swiss Economics[10] and earlier studies[11] estimates capital costs by calculation of a real annuity sum defined as:

$$(2) \quad Capex_t = \sum_{s=t-T}^{t} I_s \left(\frac{r}{1 - \left(\frac{1}{1+r}\right)^T} \right)$$

[10] Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, pp. 24-27.

[11] Frontier, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July. Sumicsid (2009), International Benchmarking of Electricity Transmission System Operators e^{3}Grid Project, Final Report, P. Agrell and P. Bogetoft, 3 September.

where: $Capex_t$ *is* the capital charge in period t, I_s is an investment stream after inflation and currency adjustment, *r* is a real interest rate (as opposed to the nominal discount rate in (1)) and *T* is the time period for the life of the asset.

A standard real interest rate is used, standard lifetimes for different asset classes are used and (given data limitations) the inflation adjustment uses the consumer price index for the different jurisdictions. All amounts are converted to Euro values in a specified year using average exchange rates.

This formulation calculates a constant real annuity for each investment over the life of the investment and then adds the annuities for each investment to form a total real capital cost defined as Capex.

Another approach is to calculate capital costs by applying a rate of return to an asset base and including a provision for depreciation. The asset base is rolled forward each year after deducting depreciation and adding new capital expenditure (the perpetual inventory method).

Frontier and Consentec[12] in a 2016 study for ACM and Jamasb et al, in a 2007 study for the Council of European Energy regulators, used this approach.[13] The Frontier and Consentec study used fully standardised capital costs. The Jamasb et al study used a common rate of return of 7 per cent but did not standardise depreciation rates or account for the age of assets and inflation differentials were not fully accounted for (see also Section 2.1 above).[14]

[12] Frontier and Consentec (2016) Gas TSO efficiency analysis for the Dutch transmission system operator: A report prepared for ACM, January.

[13] See Jamasb,T., D. Newbery, M. Pollitt, T. Triebs (2007) 'International Benchmarking and Regulation of European Gas Transmission Utilities: Final Report' (Prepared for the Council of European Energy Regulators (CEER) – Task Force on Benchmarking of Transmission Tariffs).

[14] Ibid, p. 27 and 34.

3 STANDARDISATION OF CAPITAL COSTS

3.1 Advantages and disadvantages of standardisation of capital costs

A key issue, when benchmarking across jurisdictions, is whether and how the capital charges for the cost of capital from different jurisdictions should be standardised.

The main reason for standardisation is that for an efficiency study the focus should be on comparing like with like. If there are material differences in the allowed rates of return, depreciation allowances and bases on which asset values are formed embedded in the real cost measure, then like will not be being compared with like in terms of quantities. Without standardisation of key parameters it is difficult to measure the distance from the production or cost frontier and indicate what the true efficiency shortfalls are.

A qualification to this perspective is that regulated entities may have chosen a different mix of operating and capital expenditure than if relative prices assumed for standardisation purposes applied. This in turn may affect the conclusions from efficiency analysis. For example, if the rate of return, for benchmarking purposes, is set much lower than what applied for some TSOs and, if in place, would have meant a lower amount of operating expenditure relative to capital expenditure, then such TSOs may appear to be less efficient then their true efficiency position. The converse would apply where the rate of return was set materially above what applied for some TSOs.

The extent to which this is an issue would depend on the materiality of differences in rates of return and the sensitivity of capital expenditure decisions to different rates of return. The issue is essentially an empirical one and could only be fully resolved by comparison of results using standardised parameters and country-specific regulated returns and approaches to deprecation and asset valuation. This would require a comparison of results using standardised parameters and country specific, including time specific, rates of return and approaches to depreciation and asset valuation.

For clarity, standardisation of capital costs assumes that any behavioural responses to different capital cost parameters would have no material impact on the conclusions of an efficiency study based on standardisation. Our a priori assessment is that there is likely to be relatively limited scope for TSOs to change their input mixes in response to different relative prices for operating and capital expenditure and so standardisation is a reasonable default approach. This is particularly the case where regulatory arrangements in effect provide strong assurance that expected returns will be realised.

However, the materiality of behavioural responses is an empirical issue that to our knowledge has not been investigated in relevant benchmarking studies. If an empirical study was done comparing the results from a standardised versus a non-standardised approach and found the relative rankings to be the same then this would provide support for the use of standardisation in the future, thereby simplifying the benchmarking process.

As noted, we consider that standardisation is a reasonable default position. However, the issue of whether different cost of capital parameters would have led to different decisions about the mix of capital and operating inputs could be examined as a separate study if regulators were concerned about this issue. For example, if standardised capital costs were lower than actual capital costs because a lower rate of return is used with standardisation and the entity with high actual capital costs chose to have low capital inputs and high operating costs (i.e. there was a material behavioural response in terms of choosing the mix of capital and operating inputs) then the results associated with standardised parameters could be biased.

In addition, different jurisdictions will use different approaches for asset valuation which would lead to different implied asset lives given depreciation provisions and in effect mean that like-for-like comparisons were not made. The depreciation provisions, used in many regulatory decisions, are also likely to be influenced by accounting conventions and approaches could differ even if asset lives were the same.

The use of standardised asset lives for different types of assets is considered to be a better assumption than lives implied by accounting asset values and accounting conventions for depreciation. This is particularly true given the long physical life of many network assets and the focus of regulatory decisions on ensuring the return of capital to investors.

We note that some authors have justified a standardised return on capital by reference to integrated capital markets. We do not agree with that perspective as the degree of integration has not been constant over time or across jurisdictions and the form of regulatory arrangements can mean that different allowed rates of return are appropriate for financing efficient investment. However, as noted, we do not think that justification is needed to support standardisation of capital charges. The use of country-specific capital charges would also make it more difficult to interpret the results.

We also note that, in addition to standardising capital costs, Sumicsid and Swiss Economics (2016)[15] and Frontier Economics, Consentec and Sumicsid (2013)[16] standardised the price of labour in operating costs before converting operating costs to real common currency terms using a CPI and average exchange rates. The rationale for standardisation of price components for labour is the same as for capital costs.

3.2 Approaches to standardisation of the capital input

If standardisation is implemented for capital costs there are four basic options for measuring the capital input.

- The real user cost approach which applies an appropriate measure of the cost of capital services to an asset base each period.
- The annuity approach which calculates a periodic (typically annual) capital charge comprising a return on capital component and return of capital component to recover the cost of an investment over it specified life.
- A monetary measure of the stock of real depreciated capital.

[15] Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, pp. 23-24.

[16] Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, pp. 55-56.

- A physical measure of the depreciated capital input.

These measures are described briefly below. Considerations in choosing a depreciation rate and a rate of return are presented in Sections 4 and 5. Considerations in determining an opening asset or investment value are considered in Section 6.

3.2.1 Use the real (constant price) user cost of the capital services of the asset

To understand the relevant concepts, it is helpful to first draw a distinction between capital input quantities and the cost of the services of capital inputs. This can be explained by first considering the use of capital input indexes in partial and total factor productivity analysis.

When measuring capital quantity indexes for the purposes of measuring capital efficiency and total factor productivity, capital input quantities refer to a real value of the depreciated asset base, K. Referencing formula (1) the capital price index is q which should represent as closely as possible the aggregate price of investment goods. With this deflator, the value of the asset base could be expressed in real terms, adjusted for changes in the price of investment goods, and would automatically be adjusted for depreciation and defined as K. However, when the capital input is combined with a labour input, to form an overall input, the inputs are weighted by respective cost shares to calculate a total factor input.[17] The cost shares for this total factor input for capital are calculated by applying the bracketed term $(n + \delta - \Delta q/q)$ in equation (1) to an estimate of the asset value (qK).

However, when DEA cost efficiency analysis is undertaken or cost functions are estimated, the focus is on capital cost charges rather than a measure of the capital quantity. In this case, the term $(n + \delta - \Delta q/q) \times qK$ is the nominal charge for using capital and can be converted to a real charge or real user cost, in terms of the price of investment goods, by dividing by q. Thus equation (1) can be applied to an estimate of the RAB measured in real terms to define a measure of the real charge or real cost of capital services. We define this concept as the real user cost approach. Clearly this approach requires a consistent and appropriate measure of the RAB (i.e. K) as well as measures of the opportunity cost of capital and depreciation rates.

This approach can be implemented with assumptions or data for n, δ, q and K; where n refers to the nominal weighted average cost of capital (WACC) and δ to the allowed depreciation rate. q and K would differ across countries but be expressed in terms of a common currency. The value of a starting K could be established in a number of ways as discussed in Section 6.

For benchmarking purposes, the RAB and allowed depreciation should be measured on a consistent basis and the real RAB should be measured using a capital goods deflator. However, the nominal return n should include an inflation compensation component from the investors' perspective, which is usually assumed to be reflected in the consumer price index. Section 6 provides an explanation of this proposition.

An alternative approach for estimating the component $(n + \delta - \Delta q/q) \times qK$ is to deduct operating expenditure from the relevant revenues. Then the real user cost can be calculated by dividing by q, a relevant capital goods deflator. However, this approach avoids the issue

[17] Note that the definition of totex in Sumicsid and Swiss Economics (2016), Frontier and Consentec (2016), Frontier Economics, Consentec and Sumicsid (2013) and Sumicsid (2009) is simply the sum of real operating cost and real capex (capital cost) which differs from the specification for productivity indexes.

of standardising the rate of return n and the depreciation rate δ as different jurisdictions will use different assumptions for these parameters.

The problems with the approach of calculating the real user cost of the capital services mainly relate to ensuring that the real RAB or measure of K is defined on a consistent basis and that it reflects actual costs incurred. As noted, regulators may adopt various approaches to depreciation and asset valuation and the asset values may not necessarily reflect actual expenditures less accumulated depreciation. For example, asset values may be based on historic cost, indexed historic cost or replacement values. In addition, it may not be possible to obtain a suitable investment goods deflator for all jurisdictions.

Ideally depreciation and methods of asset valuation should be standardised and reflect actual expenditures. This would mean that the RABs would need to be re-estimated.

Note that the reason that historic (actual) expenditures are relevant is to ensure that there are no windfall gains and losses if, for example, replacement values were used, as this would violate the NPV=0 condition. In addition, in assessing efficiency it is relevant to consider actual rather than hypothetical expenditures.

As highlighted in Sections 2.2 and 2.3, there are many forms of standardisation of depreciation that are consistent with the NPV=0 principle and straight-line depreciation (the most common form) is largely an accounting based convention that is not critical and often not appropriate for undertaking efficiency analysis.

If the RAB is re-estimated to be on a consistent basis for benchmarking purposes the depreciation provisions should be specified to be consistent with the NPV=0 principle.

3.2.2 Annuities

An annuity is a series of periodic payments over a defined period such that the present value of the stream of payments, calculated using a specified discount rate, is exactly equal to the initial value of the investment when it occurs. We define this as the annuity approach.

The annuity payments include both a return on capital and a return of capital over the period of the annuity i.e. an annuity payment represents a total capital charge in each period. Annuities can be specified in highly flexible ways in that the payment schedule could take any form as long as the NPV=0 condition is satisfied for the specified discount rate. The annuity could be specified to be constant in nominal or real terms or indexed to increase or decrease in nominal or real terms and could contain higher charges at the start of the period or the end of the period. Annuities can accommodate any form of the payment profile as long as the NPV=0 condition holds.

The most common forms are for a fixed payment (in nominal or real terms) or an indexed payment that increases over time (in nominal or real terms). If a nominal (real) discount rate is used the payments are in corresponding nominal or real terms.

The basic formulas for a fixed payment and indexed payment annuity are as follows:

(a) Constant capital annuity—the annuity is specified as a constant amount over time (i.e. not escalated annually):

(3) $PMT = PV\left[\frac{r}{1-\left(\frac{1}{1+r}\right)^{ta}}\right]$

where:

PMT = annuity payment per period

PV = present value of assets (existing assets and/or future capex)

r = discount rate (real or nominal) applicable

ta = term of the annuity.

(b) Indexed capital annuity—the annual payment is escalated annually by a specified indexation rate (such as the CPI) beginning from the first year of the annuity. The annuity amount for a given period t is expressed as follows:[18]

(4) $PMT_t = PV\left[\frac{r-g}{1-\left(\frac{1+g}{1+r}\right)^{ta}}\right](1+g)^{t-1}$

where:

PMT = annuity payment per period

PV = present value of assets (existing assets and/or future capex)

r = discount rate (real or nominal) applicable

g = escalation rate for the annuity

ta = term of the annuity

t = the period of interest.

For the purposes of benchmarking, we consider the constant capital annuity in real terms is appropriate for efficiency analysis and note it has been used in several of the studies referred to in Section 2. Different forms of indexation are relevant if there are additional policy reasons for indexing, for example to reflect the growth of customers and their capacity to pay for assets over time. Any indexation factor can be used but different factors will have implications for starting point prices to satisfy the NPV=0 condition.

The constant price capital annuity requires a common discount rate and common asset values and asset lives for implementation. It is simple to understand, avoids discretion in implementation and it puts the price component relating to the quantum of investment on a standard basis. The PV component in the formula represents the constant price cost component that can differ across jurisdictions reflecting different input requirements.

[18] The PMT function in Microsoft Excel calculates a constant annuity consistent with the constant annuity formula but does not allow for direct calculation of an indexed annuity.

As in the case of the user cost approach in 3.2.1 the asset values in the formula should reflect the value of what was actually spent in nominal terms (i.e. historic costs) and not replacement values. Thus, an approach that tries to calculate nominal or real (assuming an appropriate deflator and corresponding discount rate are used) investment streams and uses standard asset lives and a common corresponding nominal or real discount rate will be suitable.

This approach requires the same consistent approach to establishing investment expenditures that reflect actual expenditures as explained in Section 3.2.1.

3.2.3 Use the real (constant price) depreciated value of the RAB

An alternative to using the real cost of capital services as an input is to use a measure of the capital input in quantity terms i.e. deflate the asset value of the capital input by the deflator q as defined in equation (1). This would express the value of the asset base in real terms, based on changes in the price of investment goods, and would automatically be adjusted for depreciation. It should be noted use of this approach would provide information on technical efficiency rather than cost efficiency and would require inclusion of opex and capital as separate inputs.

This approach also faces the problems that depreciation is not automatically standardised and asset values could differ substantially across businesses. In addition, it may not be possible to obtain a suitable investment goods deflator for all jurisdictions.

Asset bases could be re-estimated to address these problems. However, this approach is not typically used in cost efficiency DEA or cost function studies where there is a focus on costs rather then input quantities. Nevertheless, this approach may be useful for examining the similarity of cost efficiency results to technical efficiency results based on using capital stock implicit quantity data.

3.2.4 Use of physical capital quantities

An alternative approach to 3.2.3 is to use a physical measure of capital inputs rather than focussing on the real capital asset value. This in effect avoids the issue of standardisation of the return on capital and depreciation and more directly captures the capital input quantity variable. However, like the approach in section 3.3.3, this approach would only provide information on technical efficiency and would require separate inclusion of the opex and capital variables.

For example, the main capital inputs for a network energy business could be defined in terms of their capacity and, in the case of conductors, their length.

If this is not feasible, for the DEA analysis, given the number of observations, the different capital inputs could also be combined into a single capital quantity index but this would require information on their contributions to cost. Cost shares could be calculated for different types of assets using equation (1). This approach is adopted by the Australian Energy Regulator in its annual benchmarking reports for electricity networks.

However, implementing this approach also faces the issue of distinguishing between capital inputs and outputs, e.g. the input measure would need to be sufficiently different to the normalised grid a measure of physical output.

As for the approach described in section 3.2.3, this approach could be used to test the compare cost efficiency results with technical efficiency results.

In theory, a physical measure of the capital stock could be multiplied by an appropriate deflator to form an estimate of a standardised asset value. This could then be used form a measure of the annual user cost of capital as set out in section 3.2.1. This could then be used in an assessment of cost efficiency. However, deriving an appropriate deflator series would likely be problematic.

Table 1 contains a summary of advantages and disadvantages in relation to standardisation of capital costs and the four methods for standardisation of capital costs.

Table 1: **Advantages and disadvantages of standardisation of capital costs and different methods**

Issue/method	Advantages	Disadvantages	Comment
The case for standardisation	Allows like-for-like comparisons in efficiency assessments – corrects for different methods of asset valuation, depreciation and return on capital that could distort efficiency comparisons.	Does not recognise that input choices may be affected by different capital cost parameters.	The impact of different capital cost parameters on input choices could be examined as a second stage where relevant and by sensitivity analysis
Standardisation of capital input			
Real user cost of capital services and asset base method	Standard, well understood approach in regulatory decisions and efficiency studies for measuring the cost of capital services. Approach is more likely to be reflected in most regulatory decisions and data. Easy to implement if data are available.	Asset values and depreciation methods may vary substantially and not reflect actual costs. Requires information on the rate of return, depreciation rate, capital goods deflator and historic asset values. Asset values may need to be re-calculated with consistent data.	Historic asset values are needed for consistency with the NPV=0 principle and like-for-like comparisons.
Annuity	Can be based on investment stream data rather than requiring a starting RAB value on a consistent basis. Consistent with the real user cost of capital services approach and may be easier to use when there is missing investment data or data needs to be adjusted for like-for-like comparisons. Flexible capital charge profiles can be easily specified.	Need sufficient investment data on a consistent, historic cost basis.	Closely related to the real user cost of capital services and asset base method.
Real depreciated RAB	Only requires estimate of real RAB rather	Would only provide information on	May be useful in testing the sensitivity of

	than the user cost of capital services. Similarities to some approaches used in calculating total factor productivity indexes.	technical efficiency Would require inclusion of opex and capital as separate variables. Asset values may need to be re-calculated with consistent data. Real capital services may be a better measure of the capital input than the quantity of the capital stock. .	conclusions using other methods.
Physical capital	Only requires a measure of physical capital capacity. Similarities to some approaches used in calculating total factor productivity indexes.	Would only provide information on technical efficiency Would require inclusion of opex and capital as separate variables. Different measures of physical capital need to be combined into a single capital input. There are likely to be different views about how to measure physical depreciation. While DEA will produce a technical efficiency score when physical inputs are used it is not possible to obtain a cost efficiency score without cost information. Developing an appropriate deflator series to form an estimate of asset value that could then be used to form a standardised user cost would be problematic.	May be useful in testing the sensitivity of conclusions using other methods.

4 MEASURING DEPRECIATION

There is a myriad of ways to specify depreciation to ensure that the NPV=0 principle applies.[19] The examples below illustrate the application of four basic depreciation methods as well as an annuity. The four types of depreciation are: straight-line depreciation; front-end loaded (accelerated) depreciation; back-end loaded depreciation; and one-hoss shay depreciation (where all of the depreciation occurs in the final period).

The form of depreciation chosen in regulatory decisions depends on the objectives of the regulator. Straight-line depreciation entails the deduction of a constant proportion of an asset usually reflecting the inverse of the life of the asset when the investment first occurs. It is the most common form of depreciation used in accounting and regulatory decisions.

Accelerated depreciation may be relevant where there is a concern to recover most of an investment over a shorter period than implied by straight-line depreciation because of concerns about asset stranding. Back-end loaded depreciation may have relevance where there is an objective to increase capital charges over time because of affordability or excess capacity issues. One-hoss shay depreciation has relevance for some structural assets with very long lives where there i minimal depreciation until near the end of the life of the asset and there is an interest in reflecting physical depreciation.

As noted in Section 2.3 an annuity in effect endogenises the depreciation charge depending on the discount rate that is used and the extent to which the annuity is defined in nominal or real terms and indexed to increase or decrease.

The examples, presented below, make the following assumptions:

(a) All values are expressed in real terms.

(b) Initial purchase price of asset = $1000.

(c) Asset life = 5 years.

(d) Allowed real rate of return = 10 per cent.

(e) Capital charges are received at the end of each period.

The different outcomes are shown in Table 2. The present value is evaluated at the beginning of Year 1.

The streams of capital charges produced under the four methods of depreciation and a constant real annuity are all equivalent in a present value sense, satisfying the NPV=0 principle. Regardless of the depreciation method applied, depreciation over five years must total $1000 in order to satisfy the NPV=0 principle.

Note that straight line depreciation does not lead to a path of constant real capital charges as is the case for the constant real annuity. Note also that straight line depreciation implies higher real capital charges then the annuity approach in the early time periods.

[19] See Queensland Competition Authority (2014), Financial Capital Maintenance and Price Smoothing, Information Paper, February.

Table 2: **Comparison of recovery of capital with different depreciation methods**

Method	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
1. Straight-line depreciation					
Opening asset value	$1000	$800	$600	$400	**$200**
Depreciation	$200	$200	$200	$200	**$200**
Return on capital	$100	$80	$60	$40	**$20**
Capital charge	**$300**	**$280**	**$260**	**$240**	**$220**
Present value	$1000				
2. Front-end loaded depreciation					
Opening asset value	$1000	$700	$450	$250	**$100**
Depreciation	$300	$250	$200	$150	**$100**
Return on capital	$100	$70	$45	$25	**$10**
Capital charge	**$400**	**$320**	**$245**	**$175**	**$110**
Present value	$1000				
3. Back-end loaded depreciation					
Opening asset value	$1000	$900	$750	$550	**$300**
Depreciation	$100	$150	$200	$250	**$300**
Return on capital	$100	$90	$75	$55	**$30**
Capital charge	**$200**	**$240**	**$275**	**$305**	**$330**
Present value	$1000				
4. One-hoss shay depreciation					
Opening asset value	$1000	$1000	$1000	$1000	**$1000**
Depreciation	$0	$0	$0	$0	**$1000**
Return on capital	$100	$100	$100	$100	**$100**
Capital charge	**$100**	**$100**	**$100**	**$100**	**$1100**
Present value	$1000				
5. Constant real annuity					
Annual charge	$263.8	$263.8	$263.8	$263.8	$263.8
Depreciation	163.8	180.2	198.2	218.0	239.8
Return on capital	100	83.6	65.6	45.8	24.0
Capital charge	**$264**	**$264**	**$264**	**$264**	**$264**
Present value	$1000				

The front-loaded and back-loaded depreciation approaches are not widely used in efficiency studies and there is no clear guidance for establishing the depreciation patterns. However, some statistical agencies use a hyperbolic pattern where the curvature of the age-efficiency profile of an asset can be varied between straight line depreciation and one-hoss shay depreciation.

The annuity approach endogenises the depreciation component of the capital charge but there is flexibility in specifying the annuity charge by indexing it to increase or decrease over time, provided the NPV=0 condition is satisfied (or to specify other patterns). The annuity approach is easy to implement in efficiency studies and particularly useful when used with investment stream data. However, the approach is often not well understood.

There is not likely to be a lot of difference on costs of using either straight line depreciation with a user cost formulation or the annuity approach which endogenises depreciation in either regulatory decisions or efficiency studies.

If there is a concern to recognise the real productive capacity of an asset over its remaining life, the depreciation provisions should reflect any deterioration in physical capacity and the shortening of the remaining life of the asset, and the effect that these two factors have on the present value of the future productive potential of that asset. However, if businesses have a similar mix of assets with similar age profiles the results are not likely to be sensitive to the exact form of standardised depreciation that is used.

Table 3 contains a summary of advantages and disadvantages of different methods for standardisation of depreciation.

Table 3: **Advantages and disadvantages of different methods for standardisation of depreciation**

Issue/method	Advantages	Disadvantages	Comment
Straight line	Standard widely used and well understood approach for specifying depreciation in regulatory decisions and efficiency studies. Approach is more likely to be reflected in most regulatory decisions and data. Easy to implement.	Straight line assumption is an accounting convention that does not necessarily reflect physical depreciation or economic depreciation.	Widely used.
Front loaded	Accelerated depreciation may be relevant if there is a need to recognise high asset stranding risk.	Not clear how to specify degree of front loading that should apply.	Not normally a feature of efficiency studies.
Back loaded	Back loading of depreciation may be relevant if physical depreciation occurs more slowly than for straight line depreciation. Back loading may also be preferred when there is a preference for capital charges to increase more over time than occurs for other methods.	Not clear how to specify degree of back-loading that should apply.	Not normally a feature of efficiency studies, except where physical depreciation approximates a one-hoss shay profile.
One-hoss shay	May be preferable if physical depreciation occurs near the end of the life of assets with long lives.	May be problematical when undertaking like-for-like comparisons when asset lives differ materially across jurisdictions.	Has some relevance to productivity studies where capital quantities need to reflect the profile of the asset's actual capacity over its service life.
Annuity	The annuity endogenises the depreciation component included in the annuity charge, although there is scope to vary the annuity over time, provided the NPV=0 condition is satisfied. Convenient approach for implementation in efficiency studies.	Approach is often not well understood.	If businesses have a similar mix of assets with similar age profiles the results are not likely to be sensitive to the exact form of standardised depreciation that is used.

5 MEASURING THE RATE OF RETURN

As the rate of return and depreciation charges are being standardised, so that the focus is on comparable measures of capital services in constant prices, the use of a single average rate of return is considered to be a reasonable assumption.

The allowed rate of return that is necessary to finance efficient investment may vary over time reflecting changes in fundamental economy-wide factors as well as sector specific and regulatory circumstances. In recent times a fundamental development has been the reduction in the risk free rate of return (which is the standard starting point for pricing risky assets) and there is evidence that European regulators have been approving materially lower allowed rates of return in recent years.[20] However, the use of country-specific or time-specific rates of return is considered to be unnecessary if the focus is on the efficiency of input use and the mix of operating and capital expenditure is not materially sensitive to the different regulatory arrangements that are likely to apply in most European countries . Variability in the rates of return or depreciation rates could also make it difficult to identify efficiency differences for capital inputs. It would also be unnecessarily complex. Using a standardised return on capital and standardised return of capital across jurisdictions facilitates like-for-like treatment of real capital inputs.

The regulatory rates of return that applied at different times and in different jurisdictions were judged to be appropriate given the specific circumstances to finance the investment that occurred. If a standardised rate of return is used, an assumption is made that the quantity of investment would not change.

The issue of whether the quantity of investment would have changed if the rate of return was materially different and impacted on conclusions about efficiency could be examined separately where relevant and used to qualify the findings of the first stage efficiency analysis. Such an approach could also provide useful information when considering allowed rates of return for future regulatory decisions. However, where regulatory institutions have broadly similar regulatory arrangements and levels of market development we expect there would be limited impact on investment decisions, particularly where the regulatory arrangements in effect mean there is limited risk that investors will not receive the regulated return on and of capital.

We consider it is appropriate to use a single average rate of return that applies for the whole period under consideration and across all jurisdictions as a default position, particularly if it is combined with allowed depreciation in an annuity type calculation. The alternative would be to specify different rates of return related to both countries and specific periods. This is feasible but likely to be resource intensive, probably unnecessary, and likely to make it more difficult to make like-for-like comparisons. The issue of whether standardisation of capital (and operating) costs should be implemented could be further tested as a sensitivity analysis by comparing the results where standardised results were compared to results where regulatory WACCs differed across jurisdictions and time periods to reflect what was actually allowed. (See also discussion in Section 3.1 in this paper which explained that if an empirical

[20] Ernst & Young (2013) 'Mapping power and utilities regulation in Europe', p. 17.

study was done comparing the results from a standardised versus a non-standardised approach and found the relative rankings to be the same then this would provide support for the use of standardisation in the future, thereby simplifying the benchmarking process.)

However, our a priori assessment is that relevant real returns are not expected to change to such an extent over time that cost comparisons across jurisdictions would be materially affected and so the choice of a base year is not considered critical.

The rate of return could be established by choosing parameters in a WACC measure based on average regulated WACCs in major European countries with similar regulatory institutions and a broadly similar level of market development. Estimates from major European countries or countries with more developed institutions and markets are considered to be a useful way of removing potential outlier observations. Estimates from the following studies could be used as a basis for choosing an appropriate benchmark WACC.

- Sumicsid and Swiss Economics, in their recent study of European gas transmission system operators use a real discount rate of 3 per cent. [21]
- In an appendix to several recent method decisions ACM reported nominal pre-tax WACCs for 13 European countries that ranged from 2.7 to 7.8 per cent with a median estimate of 6.44 per cent.[22] ACM adopted real before tax WACCs from 3 to 4.3 per cent, depending on the starting and ending years of the regulatory period and whether the assets were old or new.
- A recent CEER report on Investment Conditions in EU member states and Norway (24 countries) reported a real cost of debt in the range of 2.4 to 4.3 per cent,[23] a real cost of equity in the range of 5 to 7 per cent (excluding outliers for both electricity and gas companies)[24] and gearing in the range of 30 to 60 per cent.[25] The typical real risk free rate was between 1.5 and 3 per cent,[26] the typical debt risk premium was between 0.45 and 1.5 per cent,[27] the market risk premium was often in the range of 4 to 5.5 per cent[28] and standardised equity betas (with gearing of 50 per cent) were between 0.47 and 0.93 for electricity and 0.55 to 1.21 for gas (when the no-tax formula was used).[29]

Assuming a real cost of debt in the range of 2.4 to 4.3, a real pre-tax cost of equity in the range of 5 to 7 per cent and gearing of 50 per cent the real pre-tax WACC would be in the range of 3.7 to 5.6 per cent.

[21] Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, p. 26.
[22] ACM (2016), Appendix 2 to the method decision of; regional network administrators gas 2017-2021; regional grid managers electricity and others.
[23] Council of European Energy Regulators (CEER) (2017), CEER Report on Investment Conditions in European Countries, Ref: C16-IRB-29-03, 24 January, p. 53.
[24] Ibid, p. 87. It was not clear in the report if this was on a pre-company or post-company tax basis.
[25] Ibid, p. 68.
[26] Ibid, p. 41.
[27] Ibid, p. 48.
[28] Ibid, p. 62.
[29] Ibid, p. 84.

However, if the sample of companies is drawn from economies that are more developed in terms of their institutions and market mechanisms one would expect the variables and parameters to be at the lower end of the ranges reported in the CEER report and broadly similar. It is also noted that regulated energy network businesses are likely to be relatively low risk suggesting equity betas well below 1.

A real before tax WACC in the range of 3 to 5 per cent is considered to be reasonable for standardising the return on capital for a benchmarking study. Some sensitivity analysis could be undertaken but it is expected DEA results would not be sensitive to reasonable bounds for the WACC.

Table 4 contains a summary of advantages and disadvantages of different methods for standardisation of the return on capital.

Table 4: **Advantages and disadvantages of different methods for standardisation of the rate of return**

Issue/method	Advantages	Disadvantages	Comment
Standardisation of rate of return A common rate of return can be based on the average WACC for recent European regulatory decisions in countries with similar regulatory arrangements and institutions and a broadly similar level of market development. A real before tax WACC of 3 to 5 per cent is considered to be reasonable for standardising the rate of return.	Allows like-for-like comparisons of the quantity of capital inputs.	Does not recognise that input choices may be affected by different capital cost parameters	The impact of different capital cost parameters on input choices could be examined as a second stage where relevant. Where regulatory institutions have broadly similar regulatory arrangements and levels of market development we expect there would be limited impact on investment decisions, particularly where the regulatory arrangements in effect mean there is limited risk that investors will not receive the regulated return on and of capital. However, the issue of whether standardisation of capital (and operating_ costs should be implemented is ultimately an empirical one.

6 MEASURING ASSET VALUES

6.1 Introduction

In typical regulatory determinations capital charges are calculated based on applying an allowed rate of return to an approved RAB (and part of the allowed capital expenditure for that year) and specifying an allowed amount of depreciation based on assumed asset lives.

The values of the RAB can differ substantially in terms of how they were established and the extent to which they represent actual depreciated historical expenditures or a replacement value or a value based on some other benchmark or regulatory process. [30]

A recent CEER report confirms that some NRAs use historic cost, some use indexed historic cost and some use other methods to revalue assets, including a mix of historical and re-evaluated assets. [31] In Great Britain, to avoid electricity and gas transmission system businesses preferring capital solutions, a percentage of capital and operating expenditure is added to the RAB. In addition, in Great Britain some categories of capital expenditure are excluded from the RAB for electricity and gas distribution businesses.[32] Some NRAs do not include working capital in the RAB but some do.[33] The approaches to including assets under construction also vary, for example, less than half of the regulators in the gas and electricity distribution sector and in gas transmission include investment in progress in the RAB but for electricity transmission, more than half of the regulators include investment in progress in the RAB.[34] In most but not all cases capital contributions from third parties are excluded from the RAB.[35]

Different approaches to establishing the initial RAB or opening capital costs are summarised below. Subsequent sub-sections consider the key approaches in more detail.

- The depreciated historic cost (DHC) approach is simply based on historic actual capital expenditure less accumulated depreciation recovered in charges to date. The DHC approach can also be modified to index the asset base when it is rolled forward over time. However, if this is done then a real WACC should be applied to avoid double counting of inflation.[36]
- The depreciated optimised replacement cost (DORC) concept is based on using replacement (current cost) values for the assets but with adjustments to reflect optimisation of the network, including optimising out under used assets and using

[30] Oxera (2011), The opening regulatory asset base for the Dutch gas transmission system, Prepared for the NMa, April, provides a good explanation of relevant asset approaches and associated issues as also discussed here.
31 Council of European Energy Regulators (CEER) (2017), CEER Report on Investment Conditions in European Countries, Ref: C16-IRB-29-03, 24 January, pp. 117-128.
[32] Ibid, p. 102.
[33] Ibid, p. 103.
[34] Ibid p. 104 and p. 145.
[35] Ibid, pp. 109-113.
[36] If a nominal WACC is applied to an indexed RAB then a separate deduction for inflation can be made to allowed depreciation.

modern equivalent assets in terms of their service capacity, and with deductions for depreciation recovered to date. In some cases there is no optimisation undertaken.

- The 'line in the sand' approach establishes a value for the existing RAB at a point in time based on the regulatory arrangements at that time with subsequent values typically determined applying a DHC approach. In some cases 'a line in the sand' approach has been adopted after an initial asset value has been established using a DORC or similar approach.
- Base the value on a recent sale e.g. associated with privatisation and apply a DHC approach going forward.
- An alternative to using a RAB is use an investment stream and establish the sums of the annuities associated with each investment.

There may also be a need to estimate historical capital stock values to ensure a balanced data set. Two methods for establishing historical investment or capital stock values are also discussed below.

In addition to establishing starting asset values there is a need to specify how the asset base will be rolled forward from period to period and how disinvestments and the acquisition of both new and used additional assets will be included in the regulatory asset base. These matters are also considered in subsequent sub-sections.

6.2 Asset valuation approaches

6.2.1 The DHC Approach

The DHC approach values the RAB as the book value of the assets adjusted for accumulated depreciation. It is assumed that past investments have been recorded as book values based on their actual costs and then depreciated. DHC is essentially a perpetual inventory method for measuring an asset base, which requires a starting asset value, a time series of investment and an estimate of depreciation.

The DHC approach is concerned with keeping track of the return of capital to investors and so the accumulated depreciation should reflect what has been included in capital charges, rather then accounting book entries if these are not the same. For regulatory purposes, the adjustments for depreciation should not be based on physical depreciation but rather what capital has been recovered in allowed revenue or prices.

The main advantage of the DHC approach to valuation is the degree of certainty that it creates for the regulated entity that it will be able to recover the value of its actual investment (meeting the NPV=0 condition). The DHC approach creates considerable certainty for investors because it is based on readily observable accounting information relating to actual expenditure and, most importantly, it treats each new investment as a long-term contract between the regulated entity and its customers, requiring customers to pay the original cost of the asset plus an opportunity cost rate of return. Thus, the DHC approach is sometimes also referred to as the regulatory contract approach. Note also that the price paid in a recent sale, particularly in the context of privatisation, can be used in a DHC framework moving forward.

However, an issue with the DHC approach is ensuring that actual capital expenditure is prudent and efficient. Strict application of the DHC approach with a locked in value of the RAB representing actual accumulated capital expenditure less depreciation would mean that customers bear the risk that investments will not be prudent, that some assets are included that are not being used or some assets are less useful because of technological developments. These problems can be addressed to some extent (subject to information asymmetries) by developing prudency and 'used and useful' asset tests when capital expenditure is included in the RAB.

For the starting point RAB, if there is reasonable evidence that some accumulated expenditure was in excess of what is considered would have been prudent to meet expected demand when installed there may be scope for some write off of part of the DHC. However, such adjustments are part of an optimisation process, which although beneficial to users of the assets at a point in time, may impact adversely on investment incentives given information problems in determining prudency and efficiency and the need to ensure regulatory commitment and consistency. Adjustments for prudency and utilisation are in effect more tightly specified and apply to the RAB itself in the concept of the DORC approach discussed below.

The use of actual accounting information greatly reduces the scope for judgement in asset valuation for DHC compared to DORC. The DHC approach is also simple and transparent and avoids the need to repeatedly calculate what an optimal network (that would never be built) would be.

The use of prudency and utilisation tests re-introduces the need for judgement but this could be restricted to incremental capital so that there would not be a credible challenge that regulatory risk has been realised by unexpected claw back arrangements. Consultation processes can be developed with major users to help ensure capital expenditure is economically efficient and so DHC provides more scope than DORC for customer engagement in evaluating future capital expenditure. With a DHC approach the scope for variability in asset values is also greatly reduced compared with DORC leading to greater stability in allowed revenues and prices

Note that an issue in relation to adjusting an initial DHC value based on prudency and utilisation tests is that if a DEA study is being undertaken these adjustments should not be made because actual investments should be used to establish efficiency scores.

Note also that commitment to a credible DHC approach means that the risk to the owner of the infrastructure is greatly reduced and this should in turn be reflected in a lower allowed cost of capital.

A potential problem with the DHC approach is that historical information may not reliably reflect actual expenditure and the depreciation that has been recovered in capital charges.

The depreciation allowances in the DHC approach can also differ across regulators where asset lives and the form of depreciation are not standardised. This means that reported DHC accounting values may not be suitable for benchmarking and it is likely to be necessary to re-estimate a DHC asset base using standardised information provided there is reliable data on relevant historical investment streams.

We also note that the 'capex break methodology' described in Section 3.6 for estimating missing historical investment streams could be used to establish an initial DHC value and that the initial DHC value will be less important the longer the time series for investment that is available, due to capital depreciation.

6.2.2 The DORC Approach

DORC is defined as the depreciated cost of replicating the system using modern equivalent asset (MEA) values in the most efficient way possible from an engineering and economic perspective, given the network's service capability and usage. DORC first requires a valuation based on optimised replacement cost (ORC) and depreciation is then deducted. Depreciation is typically based on the age of the existing assets and their residual useful life. Redundant assets are not recognised and adjustments are made to remove excess capacity.

The ORC approach has the same conceptual basis as a total service long run incremental cost (TSLRIC) valuation (often used in regulation of the telecommunications sector) assuming a valuation based on the use of the same modern equivalent assets to provide a defined service. The underlying rationale for the use of a DORC or TSLRIC concept is primarily based on assuming either a hypothetical new entrant or hypothetical efficient operator who is able to use the most efficient technology and network. The rationale is that capital service charges should not exceed what an efficient entrant would charge based on a modern technology with equivalent capacity. If they did this could lead to inefficient bypass.

The DORC approach assumes costless entry and exit (perfect contestability). However, given the existing assets are sunk it is not credible to assume the post entry price will necessarily be maintained at a level to recover the ORC value since the incumbent could reduce price substantially given its sunk costs. The prospect of such an outcome for the entrant would in turn deter entry so, that in these circumstances, inefficient bypass is not feasible even if DHC exceeds ORC.

However, the main problem with the DORC approach is that it is not consistent with adhering to the NPV=0 principle. The use of replacement cost to value assets can lead to windfall gains and losses based on the value of a network that would never be built. In addition, a DORC approach increases risk for the investor which is likely to be problematical when the cost structure is dominated by large sunk assets.

The application of DORC has the following additional weaknesses:

- it requires considerable information and judgement which is often not made transparent and which leads to large asset value ranges – in effect it cannot be audited objectively;
- it typically does not take due account of economies of scale in building capacity such that is it is optimal to build some capacity for future demand that will be unutilised until that demand is realised;
- it may lead to instability in the regulatory arrangements if there are windfall gains as consumers insist on price restraint.

DORC valuations may have some relevance in establishing an initial asset base when the historical accounting information is unreliable but in practice DORC valuations by themselves have often been substantially discounted to establish a RAB value.

For example, in Australia, the DORC concept was adopted in a number of contexts when independent regulation was introduced in the 1990s as most regulated network businesses, a that time, were government owned and asset value records were not reliable. The DORC concept was advocated based on the efficient entry rationale and because it offered a means of establishing an initial value with some degree of objectivity. However, DORC applications were implemented with considerable discretion such that in many cases DORC valuations were lowered in order to limit regulated prices. As regulatory re-sets occurred the problems with DORC became more apparent and 'a line in the sand' approach was adopted for electricity network businesses (in 2004) airports (in 2005) and telecommunications (in 2009). This means that the value of the RAB has subsequently been locked in based on existing RAB values, but with new capital expenditure reviewed to determine if it is efficient prior to being rolled into the RAB.

In relation to the United Kingdom the following has been noted:[37]

> "The focus on re-valuing sunk assets to promote infrastructure-based competition occurred not only in Australia, but also internationally. For example, in the UK in 1997, Ofcom's predecessor Oftel shifted its cost accounting methodology from historic cost accounting (HCA) to current cost accounting (CCA), premised on the need to promote additional access infrastructure competition, which was thought to be best achieved by basing costs on those of a new entrant. It was anticipated that the subsequent upward re-valuation of existing assets would be counterbalanced by the emergence of strong facilities-based competition. However, when by 2004 this had not emerged, Ofcom concluded that BT had been earning a return above cost on its pre- 1997 assets and subsequently undertook measures to prevent further over-recovery on the pre-1997 assets.

It is also notable that in the United States historic cost approaches to asset valuation have been preferred to market based approaches for utilities following the Supreme Court Hope Case decision in 1944.[38] Reflecting this decision, there is a strong commitment to the recovery of capital and the realisation of reasonable returns which contributes to the prevalence of rate of return regulation in the United States.

6.2.3 Recent sale values

Recent sale values can be used to help value the RAB, for example, sale values for relevant monopoly assets when privatised. However, the main problems with this approach are that the privatised entity often has substantial non-regulated business and the sale value can reflect expectations of earning above normal profits, particularly where allowed rates of return are expected to exceed the cost of capital. If expectations of out-performance are reflected in the sale price of a regulated entity and the value is included in the RAB, then

Australian Competition and Consumer Commission (2009), Review of 1997 Guide to Telecommunications Access Pricing Principles for Fixed Line Services, Discussion Paper, December.

[38] Available at https://supreme.justia.com/cases/federal/us/320/591/case.html.

investors would in effect be doubly rewarded by receiving both a higher allowed return on and return of capital from the RAB and additional profits from reducing costs or increasing outputs.[39]

6.2.4 Investment streams and annuities

An alternative to using direct measures of capital costs based on applying rates of return and rates of depreciation to a consistent measure of the RAB is to establish the real value of long term investment streams and annuities to recover the cost of the investment streams. This approach has been used in the studies by Sumicsid and Swiss Economics (2016), Frontier and Consentec (2016) and Sumicsid (2009) described in Section 2.1 above.

Sumicsid sets out the approach as follows:[40]

The average lifetime of any investment basket for any operator, used in the annuity calculations for standardised capex (as defined in the Introduction of this paper) is set to the weighted average life of their investments undertaken in the same year:

$$(5) \quad T_{it} = \sum_k \left[\frac{T_k \, w_k \, x_{ikt}}{\sum_k w_k \, x_{ikt}}\right]$$

where, T_{it} is the average weighted lifetime for assets of TSO i in year t, for x *(number of)* assets of type k invested by TSO i in year t, with normalised capex weights of w_k and standardised asset lives of T_k.

The annuity factor α_{it} is then calculated based on the weighted average asset life T_{it} and a real interest rate of r :

$$(6) \quad \alpha_{it} = \frac{r}{1-(1+r)^{-T_{it}}}$$

The capital expenditure in each period is then the sum of the annuities for that year for all investments that have been made to date.

$$(7) \quad Capex_{it} = \sum_{s=t_0}^{t} I_{is} \, \alpha_{it}$$

where I_{is} is the investment stream for TSO i and time s after inflation and exchange rate correction and t_o is the initial investment period.

For benchmarking purposes, the capital expenditures should be expressed in historic cost terms and ideally converted to real magnitudes using a capital goods deflator. The real interest rate should be the relevant nominal interest rate adjusted for inflation as measured by the consumer price index (see Section 4 for an explanation).

[39] Oxera (2011), The opening regulatory asset base for the Dutch gas transmission system, Prepared for the NMa, April, p. 8.

40 Sumicsid (2009), International Benchmarking of Electricity Transmission System Operators e3Grid Project, Final Report, P. Agrell and P. Bogetoft, 3 September, p. 61. See also Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, pp. 58-60 and Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, pp. 24-27.

We consider this to be an attractive approach given it ensures NPV=0 and comparability of the quantity of inputs and is relatively easy to implement. It also enables a tractable means of addressing deficiencies in data availability as described in the following section.

6.3 Estimating historical investment values

6.3.1 Introduction

We consider that it is important to use an asset value that reflects what was actually spent on regulated assets and this implies using either a DHC approach or an investment stream/annuities approach that use actual expenditures and standardised depreciation.

To achieve standardisation of asset values it is likely to be necessary to re-construct asset bases to reflect actual expenditures, standardised depreciation and ideally indexes that reflect capital goods inflation.

Relatively long investment time series are needed to re-construct asset bases or to implement the investment stream/annuities approach (described in Section 3.2). An issue that has arisen in the past is that the investment time series does not extend over a sufficiently long time horizon.

Some approaches to estimating early investment data are described below.

6.3.2 The 'capex break methodology'

Frontier Economics et al [41] have addressed the problem of missing early investment data by developing a generic 'capex break methodology'. The capex break methodology contains the following steps: [42]

(1) Estimate a 'capex grid size' for the periods prior to when investment data are available and from when investment data are available. The capex grid size is defined as the number of different types of physical assets multiplied by their cost weights and multiplied by a relevant annuity factor (the annuity factor depends only on the interest rate and period for cost recovery).

(2) Calculate standardised capex (based on the annuity method) for the period when investment data are available for the last year when data are available. Standardised capex for the last year when data are available is the sum of all the annuities for investments made up to and including the last period.

(3) Calculate the ratio of the measure of standardised capex in (2) to the capex grid size for the period when investment data are available is calculated in (1).

(4) Multiply the ratio in (3) by the capex grid size as of the last year prior to when investment data became available as calculated in (1).

41 See Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, pp. 63-64 and Frontier Economics, Sumicsid and Consentec (2013), Method Note 1: Capital break methodology – Opening Balance Adjustments, e3GRID2012 PROJECT, 28 March/ver 1.5.

42 Frontier Economics, Consentec and Sumicisid (2013), E3GRID2012 – European TSO Benchmarking Study, A Report for European Regulators, July, p. 63.

This approach is considered to be a useful means of establishing missing investment values provided that there is a reasonably long observed investment series and provided the estimates of 'capex grid size' for the earlier period are reasonably accurate. It effectively establishes a capital output ratio where the output component is a measure of standardised grid size. Improving the method would depend on whether there were better output measures available for the whole period of interest.

A limitation of the capex break methodology is that it assumes a constant ratio of standardised capex to capex grid size. This means no substitution between operating expenditure and capital expenditure in the provision of services. This is consistent with an assumption that there is no material scope of substitution between capital expenditure and operating expenditure if standardised assumptions are used for these variables.

However, the 'capex break methodology' has the advantage of being objective and transparent and has also been shown to be feasible.

We also note that the 'capex break methodology' could be used to establish an initial asset value that could be used with the application of a subsequent DHC approach.

6.3.3 Other approaches

Other approaches for establishing early investment data or an initial level of the capital stock could be based on: (i) long term relationships between output growth and investment growth; and (ii) regressions of investment against drivers of investment or assumptions about long term investment growth with backcasting to establish initial values.

Long term relationships between output growth and investment growth are a variation of the capex break methodology and not likely to be clearly superior.

However, there may be scope to explore the potential for using regressions of investment or information on long term investment growth rates to establish an initial asset value.

Berlemann and Wesselhoft provide a useful survey of the literature on estimating initial capital stock values or early investment data based on three approaches used for major sectors and at the national level in the literature.[43]

The first approach is a 'steady state' approach where the growth of GDP is specified to be equal to the growth of the capital stock and this relationship is applied using information on investment in the current period to calculate the capital stock in the preceding period. This approach is sensitive to the growth rate of GDP that is used and assumes an equilibrium relationship.

The second approach is a disequilibrium approach but argues that the growth rate of the capital stock can be approximated on average by the growth rate of investments estimated using smoothing techniques. This approach is sensitive to the end points of the investment series.

[43] Berlemann, M., and J. Wesselhoft (2014), Estimating Aggregate Capital Stocks Using the Perpetual Inventory Method – A Survey of Previous Implementations and New Empirical Evidence for 103 Countries, Review of Economics, 65, 1-34.

The third approach constructs a time series of investment by estimating a constant growth rate for investments. This approach also obtains econometric estimates of depreciation rates. This approach is highly sensitive to the initial investment observation.

Bertelmann and Wesselhoft present a fourth approach that combines various aspects of the other three approaches to try to overcome the disadvantages with these approaches. They then estimate the capital stock using their approach and the three other approaches for 103 countries.

In developing a preferred model, Berlemann and Wesselhoft follow De La Fuente and Domenech,[44] in arguing that the growth rate of the capital stock can be approximated on average by the growth rate of investments, as follows:[45]

$$(8) \quad K_{t-1} \approx \frac{I_t}{g_I + \delta}$$

Where: K_{t-1} is the capital stock in period t-1, I_t is gross investment in period t, g_I is the growth of investment and δ is the depreciation rate.

Equation (8) is implemented by first regressing the log of a long investment series ranging from time t_2 to T on time and using the fitted values from the regression to estimate I_{t1}. This helps to overcome the problem of sensitivity to initial investment values. The fitted values of the log of investments are transformed using the exponential function to provide a time series of investment from to t_1 to T. The first value of the time series of investment is then used with estimates of the growth rate and depreciation to calculate the initial capital stock in period t_0 . The coefficient on the time variable from the regression is used as an estimate of $g_{I.}$ In addition, δ is allowed to vary with time and estimated using a regression for three asset classes (presumably a regression of the capital stock in period t less gross investment in period t on the capital stock in period t-1).

Berlemann and Wesselhoft found considerable variety in the resulting time series estimates of the capital stock for the four methods, especially in the first years but that the results converged quite quickly in the course of time, for the 31 countries where it was possible to generate capital stock series for the whole sample period (1970 to 2019) for all four methods. Berlemann and Wesselhoft noted that the comparison of the methods provided no information on which method is preferred but argued their proposed method was based on theoretical reasoning (to address key disadvantages of other approaches).

The Berlemann and Wesselhoft methodology may be resource intensive but does not assume a constant capital output ratio and appears promising.

It would be of interest to compare the results using the capex break methodology with an approach based on the Berlemann and Wesselhoft methodology.

We also consider that the default position should be to use actual data when it is available and the capex break or Berlemann-Wesselhoft approach to estimate missing values, unless actual data are only available for a few entities. This is because using forecasts rather than actual information in effect discards relevant information.

[44] De La Fuente, A., and R. Domenech (2000), Human Capital in Growth Regressions: How Much Difference Does Data Quality Make, Economics Department Working Paper 262, OECD, Paris.
[45] Berlemann and Wesselhoft, p. 6.

Table 5 contains a summary of advantages and disadvantages of different methods for establishing opening capital costs.

Table 5: **Advantages and disadvantages of different methods for establishing opening capital costs**

Issue/method	Advantages	Disadvantages	Comment
Depreciated historic cost (DHC)	High assurance that actual approved capital expenditure will be recovered on an NPV=0 basis. Lower risk should mean a lower cost of capital. Easily understood. Objective and simple to implement. Allows comparisons on a like-for-like basis reflecting actual expenditure.	Data for starting asset values or for historical investment streams may not be reliable.	Widely used. Can use capital output ratios to identify missing investment values.
Depreciated optimised replacement cost (DORC)	May be relevant in sectors where there is rapid technological change and entry barriers are low. Can help establish an initial asset value where historic data are unreliable.	Potential for large windfall gains and losses. Does not comply with the NPV=0 principle. Higher risk should imply a higher cost of capital. Hypothetical concept that is of questionable relevance when sunk costs dominate the cost structure. High reliance on judgement. Costly to implement.	Regulators have tended to make less use of the DORC approach given concerns about windfall gains and losses and extent of judgement required.
Sale value	Can help establish an initial asset value where historic data are unreliable.	May double count the potential for efficiency gains.	More realistic than the DORC approach.
Annuity from investment stream	Similar advantages as for the DHC approach. Easier to use in an efficiency study than the DHC approach.	Data for historical investment streams may not be reliable or available for all years for all TSOs.	Can use capital output ratios to identify missing investment values.

Capex break methodology for estimating early investment values	Objective, transparent and feasible provided data are available on capex grid size for period when investment data are not available.	Assumes a constant ratio of standardised capex to capex grid size.	It would be useful to compare results from the capex break methodology with results from the Berlemann and Wesselhoft methodology.
Berlemann and Wesselhoft methodology for estimating early investment values	Objective and transparent and does not require information on capex grid size or other output information.	May be resource intensive.	As above.

6.4 Rolling forward the asset base

The term 'roll–forward' refers to adjusting the asset base over time to add capital expenditure (capex) and subtract depreciation from year to year.

Once an initial asset base has been properly established then it is quite straight forward to roll it forward in a way that satisfies the NPV=0 principle. If the asset base is indexed then it is rolled forward after deducting depreciation, adding capital expenditure in the prior year, deducting asset disposals and then indexing by a suitable price index.

To satisfy the NPV=0 principle there is no need to replace forecast depreciation, for the previous period with actual capital depreciation based on actual capital expenditure. This is because the forecast depreciation is what was actually reflected in charges and the deduction will already be reflected in the RAB. If actual capital expenditure was less than forecast capital expenditure but forecast depreciation was retained, this simply means the value of the RAB when rolled over is less than if actual depreciation was used so there is in effect already an adjustment to ensure there is no over recovery of capital. The converse holds when actual capital expenditure exceeds forecast capital expenditure where the RAB when rolled over will be higher than projected for the most recent regulatory period, but the depreciation allowance was lower than implied by actual depreciation in the regulatory period.

Regulators may wish to make adjustments for the financing benefit (or cost) if forecast (and allowed) capital expenditure exceeded (or fell short) of actual capital expenditure. The financing effect arises to the extent prices reflect the application of a rate of return on and of the difference between forecast capital expenditure and actual capital expenditure over a regulatory period.

The adjustment for the financing benefit or cost can be based on assuming that the RAB is rolled forward using either forecast or actual depreciation. However, if forecast depreciation is used the net financing benefit is easier to calculate as the NPV adjustment simply relates to the financing benefit on the undepreciated investment surplus or deficit, since the forecast depreciation allowance will mean the RAB is that much lower or higher when rolled forward using actual capital expenditure. The Australian Energy Regulator and other regulators in Australia tend to use forecast depreciation when rolling the RAB forward as it is simpler and facilitates a financing adjustment where considered relevant.

The AER also considers that using forecast depreciation in combination with its capital expenditure sharing scheme provides the best balance of incentives for pursuing efficiency in capital expenditure.[46]

The use of actual depreciation can provide stronger incentives to reduce capital expenditure because of the financing benefits from underspending and financing costs for overspending but also provides incentives for regulated network businesses to overinflate their capital expenditure forecasts. Using actual depreciation when rolling forward the RAB also provides incentives to spend on assets with shorter lives – as asset life shortens, spending on the asset

[46] AER (2013) Explanatory Statement Capital Expenditure Incentive Guideline for Electricity Network Service Providers, Better Regulation, November, pp. 41-42.

becomes more akin to being fully expensed and a higher proportion of the RAB will have to be spent each year to simply maintain the size of the RAB.[47]

Table 7 contains a summary of the advantages and disadvantages of different methods for rolling forward the asset base (the decision on whether and how to index the asset base was discussed in Section (7.1).

Table 7: **Advantages and disadvantages of different methods for rolling forward the asset base**

Issue/method	Advantages	Disadvantages	Comment
Using forecast depreciation	May provide a better balance of incentives for accurate forecasts and pursuing efficiency in a regulatory context. Facilitates adjustments for correcting financing benefit or cost from difference between actual and forecast capital expenditure.	May not be necessary if forecast capital expenditures are reliable.	The issue of how to treat depreciation when rolling forward the RAB is mainly relevant for regulatory purposes rather then for an efficiency study. However, there can be incentive effects relating to whether forecast or actual depreciation is used when rolling forward the RAB.
Using actual depreciation	See above.	See above.	See above.

Asset disposals would typically be treated as a reduction in the capital stock. To elaborate, if the capital input is reduced because of an asset disposal that should mean a reduction in the value of the asset base and its productive capacity. This would mean a reduction in capital charges and hence annuity estimates to reflect the reduction in the capital value to be recovered. The revenue from any disposal should be reflected in the financial accounts and realised returns. For benchmarking the key adjustment would be to productive capacity and capital charges (e.g. annuity payments). Where TSOs do not know the individual asset value or its remaining asset life for an asset disposal, there would be a need to estimate the productive capacity and remaining asset life of the asset and ascribe a value based on this information, for example, based on the share of the asset in the total productive capacity of the TSO.

Assets acquired through mergers or used assets and upgrades should be valued at the acquisition cost and included in the regulatory asset base in the same way that new investment is included (at the purchase or acquisition price) and adjustments made to remaining asset lives and capital charges to reflect appropriate depreciation provisions.

[47] Economic Insights (2012), The use of actual or forecast depreciation in energy network regulation, Report prepared for the Australian Energy Market Commission. D. Lawrence and J. Kain, 31May.

6.5 Other considerations

There are a number of additional issues that need to be considered in forming consistent asset values across the benchmarked TSOs. Important among these are the treatment of interest during construction and capitalised labour. For projects that have a longer gestation period, the inclusion of interest during construction can be a significant part of the opening asset value. While this is more likely to be an issue for the (thermal) generation sector, it could also be important for major TSO projects and consistent treatment across the sample is desirable.

The degree of contracting out of capital construction may also vary significantly across the sample. For those TSOs that undertake significant capital construction activities in house, it will be important to include that part of labour costs attributable to capital works in the total cost of capex and to exclude it from the opex input which should only include labour associated with operations and maintenance activities. Similarly, different TSOs may have different cost allocation methodologies for allocating overheads between opex and capital. It will be desirable to measure the asset values using a cost allocation methodology that is as consistent as possible across the included TSOs.

7 CONVERTING TO COMMON MONETARY UNITS

7.1 Adjusting the RAB or investment streams for inflation

The RAB does not need to be adjusted for inflation when it is rolled over if a nominal rate of return is applied to the DHC value of the RAB. This approach is simple and can be specified to be consistent with the NPV=0 condition as well as ensuring the asset base is suitable for benchmarking purposes.

If the RAB is indexed for inflation for regulatory purposes and a nominal rate of return based on the opportunity cost of investment is applied it is necessary to make a deduction from capital charges for the double compensation of inflation that would otherwise occur. The unindexed and indexed asset base approaches can be specified to be equivalent from an NPV=0 perspective but indexation of the DAC value creates complications as to which index to use and adjustments to ensure there is not double counting of inflation.

If the RAB is indexed for inflation but a real rate of return is applied to calculate the return component for capital, double counting of inflation will not occur if the same inflation index is used for indexation and for defining the real return. However, the same inflation rate should not be used if the asset value is to be used for benchmarking purposes, as explained below.

For benchmarking purposes, one needs to reflect an asset value in terms of its real purchasing power in relation to capital quantities. That means it needs to be based on a measure of historic costs and if converted to real magnitudes it needs to be indexed by the most relevant capital or investment goods deflator.

But if one takes an investors' perspective when indexing the asset base or defining a real rate of return, the relevant inflation index is the consumer price index as this is the measure that reflects general purchasing power and is relevant for incorporation in the opportunity cost measure for an investment return.

Typically, the RAB is rolled forward based on indexing by the consumer price index and this is appropriate if one is concerned to express the value of the asset in general purchasing power terms and the focus is on ensuring the NPV=0 condition and the investors perspective.

We are not arguing that regulators should necessarily index the RAB by a capital goods price index rather than the consumer price for regulatory purposes in setting allowed revenues. However, we are arguing that such an asset base is not appropriate for benchmarking purposes and, in that case, would need to be recalculated to reflect the inflation embedded in a capital goods deflator. In practice, there may not be a material difference but this could be tested and the conceptual distinction should in any case be recognised.

As a more minor point, we note that if straight line depreciation applies, the application of a nominal return to the indexed value and the separate deduction of inflation compensation will lead to a flatter profile for capital charges than applying a nominal rate of return to an unindexed DAC. However, smoothing of charges can be done separately leading to effective endogeneity of the depreciation charges (as occurs in an annuity) but subject to satisfying the NPV=0 condition. So, there is no inherent smoothing justification to prefer an approach that indexes the RAB.

To reiterate, if the DHC is indexed as the asset base is rolled forward in order to reflect general purchasing power it should be indexed by the inflation index that is implicitly embedded in the rate of return that is applied. The relevant inflation rate embedded in the nominal rate of return is what is required to compensate investors for the effect of inflation on their general purchasing power. This is generally best measured by the consumer price index (CPI) for a country.

However, when selecting a price index for future capital expenditure (or operating costs) or if one is evaluating an investment stream by itself (rather than a DHC) then it is necessary to select the most representative price index for that cost item. This is needed in order to correctly estimate the actual costs that need to be recovered.

There is no inconsistency in rolling forward a DHC indexed by the CPI and including new nominal capital expenditure based on applying an estimate of the volume and expected inflation in capital goods. This is because the aim is to ensure the NPV=0 condition is satisfied reflecting actual nominal costs incurred and using a nominal discount rate based on the required returns for investors. The actual historic costs will already reflect actual capital costs and the indexing of the RAB converts past expenditures to a present value that reflects general purchasing power and the perspective of the investor. However, if a benchmarking study is being undertaken, from a conceptual perspective, it is preferable to index the asset base by a relevant sectoral investment deflator if it is available across periods and jurisdictions.

If there is no RAB and an investment stream is used it should be first formulated in nominal terms expressing what was spent or is projected to be spent. It can then be converted to real terms using a relevant capital goods deflator.

The discount rate should be first formulated in nominal terms from the investors' perspective (which means that it will contain an implicit component to compensate for inflation, typically measured by the consumer price index) and then an adjustment should be made for nominal capital gains (or losses) for the particular asset class. [48]

7.2 Relevant deflators

Ideally the deflators for cost categories should represent the specific costs in the relevant categories and not other costs. Thus, for capital expenditure for energy network businesses the most relevant deflator would be a deflator that represented construction and equipment costs while for operating expenditure the deflator would represent labour plus relevant intermediate goods and services costs.

Economic Insights has usually used the following approach to define the deflators for opex and the capital base for benchmarking purposes. The opex deflator has been constructed as a weighted average of several price indexes believed to be most relevant to components of opex cost. The most important of these is an index of wages and salaries (excluding bonuses). In addition, a number of producer price indexes have been used to reflect other components of opex, such as financial services, transport and materials. The capital stock deflator often used has been the net capital stock deflator for the Electricity, Gas, Water and Waste sectors

[48] See equation 1 in Section 2.4.

drawn from the National Accounts. However, the benchmarking work has focussed on businesses in Australia, Canada and New Zealand where the relevant deflators are available. It is also noted that even these deflators are not ideal as they relate to much broader sectors than just electricity networks. More industry–specific capital deflators are usually compiled by the statistical agency but may not be publicly available due to confidentiality issues associated with small samples.

We have reviewed the available deflators at Eurostat and the OECD and have not identified capital goods deflators that would be suitable for the type of capital expenditure undertaken for energy network businesses where the main cost relates to construction costs. Producer price indices are not available for goods or sectors that would be representative of construction costs or equipment investment for energy network businesses. Producer price indices are available from Eurostat and the OECD for manufacturing, industrial activities, mining and quarrying, energy, intermediate goods, investment goods, consumer goods and finished goods but the country and time coverage are not complete. In addition, none of the categories is considered to closely reflect capital costs for energy network businesses. There may be some scope to investigate the availability of capital goods deflators from the national accounts but reviewing the extent to which individual countries have such information was not feasible in this study.

We note that the benchmarking studies described in Section 2.1 all used the consumer price index to convert nominal costs to real costs but that the recent Sumicsid and Swiss Economics (2016) study undertook some sensitivity analysis using available producer price indices (the exact series was not reported) with missing producer price index data being replaced by consumer price index data.[49] The Sumicsid and Swiss Economics study also noted that sector-specific indexes only exist for a handful of countries and require additional assumptions to be used for countries outside of their sample.[50]

Under these circumstances using country–specific CPIs may be the best choice available.

7.3 Adjusting for prices across countries

If performance measurement is undertaken using data on firms in different countries, there is likely to be a need to adjust for different exchange rates.

Sumicsid and Swiss Economics (2016) and Frontier Economics, Consentec and Sumicsid (2013) used average exchange rates to adjust for cost differences across countries. The Sumicsid and Swiss Economics study also undertook sensitivity analysis of the results using purchasing power parity exchange rates. The Jamasb et al (2007) study used purchasing power parities.

Purchasing power parities (PPPs) are the rates of currency conversion that equalise the purchasing power of different currencies across the same basket of goods and services (defined in quantity terms) between countries. PPPs are commonly used to make comparisons of real variables between countries. PPPs are considered to be preferable to using market

[49] Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, p. 50.
[50] Ibid, p. 27.

exchange rates as the prices of many goods and services are not internationally traded. The use of market exchange rates can lead to misleading comparisons of real magnitudes where national price levels differ substantially across countries.

It should also be recognised that PPPs have two functions. They convert expenditures to a common currency and they also revalue expenditures at a uniform price level. The two functions are independent of each other and so PPPs can still be used for countries with a common currency as spatial price deflators to value real quantities at a uniform price.[51]

Estimates of PPPs are available from Eurostat, the OECD, the World Bank and the IMF see:

http://www.oecd.org/std/purchasingpowerparities-frequentlyaskedquestionsfaqs.htm#FAQ5

Eurostat comparisons are conducted annually, cover 37 countries and have the European Union as reference and purchasing power standards (PPS) as numéraire. Joint comparisons with OECD countries are carried out every three years, cover 47 countries, and have the OECD as reference and the OECD dollar as numéraire.[52] PPPs are also calculated for individual expenditure categories. The web page links for Eurostat and OECD are:

http://epp.eurostat.ec.europa.eu/portal/page/portal/purchasing_power_parities/introduction •

http://www.oecd.org/std/prices-ppp

The World Bank coordinates the International Comparison Programme (ICP), a global statistical initiative involving some 200 countries. It produces internationally comparable price levels, expenditure values, and Purchasing Power Parity (PPP) estimates. Eurostat and the OECD are jointly in charge of the "Eurostat-OECD region" for the ICP.

See ICP data for the year 2011 and all related information.

The World Bank ICP PPP data are the most comprehensive available and cover 179 countries including 47 Eurostat-OECD countries. PPPs are also provided for both GDP and 25 other expenditure categories, including gross fixed capital formation, machinery and equipment investment and construction investment. The latest data are for the year 2011.

To ensure the most comparable comparison of quantities the PPPs should relate to the expenditure category that is closest to the capital expenditure of energy network businesses. We consider that the construction investment category is the most suitable PPP for converting capital costs to a uniform and common price level for energy network businesses. However, sector specific PPPs may not be available for all countries and it may be necessary to use the GDP PPP.

For operating costs, the GDP PPP is likely to be the most appropriate and readily available measure for converting operating costs into a common currency.

Table 6 contains a summary of the advantages and disadvantages of different methods for inflation and exchange rate adjustment.

[51] OECD and Eurostat (2012), Eurostat-OECD Medhodological Manual on Purchasing Power Parities, eurostat Methodologies and Working Papers, p. 13.
[52] Ibid, p. 20.

Table 6: **Advantages and disadvantages of different methods for inflation and exchange rate adjustment**

Issue/method	Advantages	Disadvantages	Comment
Indexation of the RAB – typically using the CPI	May assist regulators in analysing current costs.	Need to recognise that indexation of the RAB by the CPI while maintaining purchasing power from an investor's perspective does not represent the real value of the capital input from an efficiency perspective. Need to ensure that double counting of inflation does not occur by either using a real WACC with the indexed asset base or making a deduction for inflationary gains from the depreciation allowance if a nominal WACC is used.	Need to note the different objectives of the regulatory arrangements and an efficiency study when indexing the RAB.
Relevant deflators			
CPI	Readily available for historical periods and different jurisdictions.	For an efficiency study, specific cost deflators are preferable.	The sensitivity of the results can be checked using different deflators where available but it may be necessary to use the CPI in estimating real operating and capital costs.
Specific cost deflators	Facilitate like-for-like comparisons.	Availability may be a problem.	As above.
Exchange rate adjustment			
Market exchange rates	Readily available for historical periods and different jurisdictions.	For an efficiency study purchasing power parities are preferable for making comparisons of real variables.	The sensitivity of the results can be checked using PPPs as an alternative where available.
Purchasing power	Better allows like-for-like	Less representative than PPPs for specific cost	As above.

parities for GDP	comparisons than market exchange rates.	categories.	
Purchasing power parities for construction investment	Best ensures like-for-like comparisons.	May not be available for some countries	As above.

8 DISTINGUISHING BETWEEN OPERATING AND CAPITAL COSTS

It is common for European NRAs to use a single aggregate input, namely cost, which is an aggregate of operating and maintenance costs (opex) and the opportunity cost of and return of capital employed (or 'standardised capex'). This is understandable because the resulting efficiency measures directly convey information about the scope for cost savings available through efficiency improvement.

However, the use of a single input necessarily limits the information that the benchmarking study can provide. For example, when there is only one input, allocative efficiency cannot be quantified separately from technical efficiency, which can reduce the information available to explain observed inefficiencies. If more than one input is included then results for allocative efficiency can be separated from the results for overall cost efficiency. This will provide information on how close a particular firm is to adopting an input mix that minimises its costs, given its level of technical efficiency.

We note that in their recent study, Sumicsid et al estimated a two-input variant of their base totex model, distinguishing between opex and capex on the input side and identifying separate efficiency measures for opex and capex.[53] The study concluded that totex inefficiency was distributed evenly on opex and capex in the model.

The preferred different approaches to measuring capital were described in Section 2.4 (equation 1, rental rate or user cost of a unit of capital, and equation 2, the annuity approach) and either of them could be used if operating and capital costs are treated separately.

53 Sumicsid and Swiss Economics (2016), Project E2 Gas: Benchmarking European Gas Transmission System Operators, Final Report, P. J. Agrell, P. Bogetoft and U Trinkner, 2 June, p. 48.

ANNEX 1 POTENTIAL FOR USING TOTAL OPERATING AND CAPITAL EXPENDITURE IN BENCHMARKING

For completeness in terms of options for consideration, this annex provides an outline of an alternative approach to benchmarking that uses total operating and capital expenditure rather than total operating and total capital costs (which cover the return on and return of both the existing capital stock and new investment).

We note that for Ofgem in the United Kingdom, 'totex' refers to the sum of operating and capital expenditure rather than the sum of operating expenditure and capital costs as described here.[54] This has the advantage, in a regulatory context, of recognising that the main flexibility, in improving performance, in relation to the capital input relates to capital expenditure rather than the sunk capital base.[55]

An important point to recognise is that Ofgem's use of benchmarking has been implemented **in conjunction with** an incentive scheme for totex based on the menu approach to regulation. The menu approach to regulation is designed to ensure that firms have strong incentives to reveal their true efficient costs and also to exert optimal effort to pursue efficiency over time. However, in order to design and implement an effective menu it is still necessary for the regulator to establish a reasonable estimate of efficient costs. This approach is designed to overcome the Averch-Johnson type effect by addressing the incentives to reveal efficient costs as well as incentives for pursuing efficiency over time.

Ofgem's menu approach was explained in detail in various documentation for the 2010-2015 regulatory period.[56]

In terms of quantitative assessment of totex Ofgem estimates three models as follows:

> "In its final decisions, Ofgem estimated three cost assessment models:[57]
>
> - Top down totex model (version 1) — benchmarking using regression analysis of totex (input) against a composite scale variable (CSV) of modern equivalent asset value (MEAV) and customer numbers (outputs or drivers)
> - Top-down totex model (version 2) — benchmarking using regression analysis of totex (input) against a CSV of the bottom-up drivers used in the disaggregated analysis
> - Disaggregated model/analysis — assessing disaggregated cost activities using a mixture of cost assessment techniques such as regression analysis, ratio analysis, trend analysis and technical assessment; where the approach is tailored to the activity being assessed—the efficient expenditure determined for each category is summed to get a totex value.

[54] Ofgem, Strategy decisions for the RIIO-ED1 electricity distribution price control: Tools for cost assessment, 4 March 2013, p. 10. Ofgem, RIIO-ED1: Final determinations for the slow-track electricity distribution companies—Business plan expenditure assessment, 28 November 2014, pp. 28-30.

[55] This approach does not give a TSO more flexibility than other approaches: it just recognises that the flexibility with respect to capital, for a TSO, is effectively limited to new expenditure (and disposals) given the dominance of sunk capital.

[56] Ofgem (2009), Electricity Distribution Price Review –Final Proposals – Allowed Revenue – Cost Assessment.

[57] Ofgem, *RIIO-ED1: Final determinations for the slow-track electricity distribution companies—Business plan expenditure assessment*, 28 November 2014, pp. 28-30.

> Ofgem combined all three models (with some adjustments) to determine a final estimate of expected efficient expenditure."

Ofgem also adjusts for environment factors prior to modelling and forms the benchmark for the efficient level of totex for each Network Service Provider (NSP) using the upper quartile estimated level of efficiency. It also gives 75 per cent weight to the Ofgem benchmark and 25 per cent weight to the NSP's own forecast.

The expected efficient expenditure is then used in Ofgem's Information Quality Incentive (IQI) scheme which is based on the menu approach developed for the 2010-2015 regulatory period. Under Ofgem's menu approach NSPs can choose from different combinations of allowed cost levels and profit retention shares which are designed so that NSPs proposing higher (lower) costs than Ofgem's estimated efficient costs for that NSP, receive a lower (higher) share of cost savings.

If totex is to be expressed in real terms an overall price deflator measured as a cost share weighted average of the opex and capex price indexes should be used.

An advantage of totex benchmarking is that its data requirements on the capital side are considerably less demanding – effectively only consistent data on capex are required as opposed to consistent data on asset values, depreciation rates and rates of return that would be required in benchmarking total cost (i.e. opex plus the return of capital plus the return on capital).

Another important perspective is that the cost structure of energy network businesses is dominated by sunk costs and the flexibility to improve the efficiency of capital relies on adjustments to capital expenditure rather than on capital costs in the form of depreciation and returns on capital. The point is that the regulator needs to obtain an estimate of efficient costs that the regulated entity has control over and focussing on proposed capital expenditure may be more helpful then focussing on capital costs that are dominated by an exogenous return on capital measure and existing sunk costs. Thus, it may be worthwhile considering DEA analysis using actual capital expenditure rather than capital cost in the form of the return on and return of capital.

However, a caveat with using capital expenditure instead of a measure of real capital costs or the quantity of the capital stock or its services is that it does not reflect the economic concepts in the cost or production function and does not take account of the need for lumpy expenditure profiles at times. However, the totex approach has the advantage of focussing on capital expenditure where there is scope to make changes rather than on capital costs which mainly relate to sunk costs and it may offer some additional insights for achieving cost efficiency.