Economic Benchmarking Model: Technical Report

By Regulatory Development Branch[1]

1. Background

On 29 November 2012, the Australian Energy Market Commission (**AEMC**) announced important changes to the National Electricity and Gas Rules. These changes affect the Australian Energy Regulator's (**AER's**) role in regulating energy networks. The AER commenced the Better Regulation Program to develop regulatory processes and systems in response to the rule changes. The Better Regulation Program includes consulting stakeholders on the creation of new guidelines that outline the AER's approach to assessing Network Service Providers' (**NSPs'**) expenditure proposals and to determining electricity network revenues and prices.

The AER (2012) has announced that economic benchmarking is one of a suite of assessment techniques that it is seeking to include in forthcoming guidelines in relation to expenditure forecast assessment.

The AER has since asked the Regulatory Development Branch (**RDB**) of the Australian Competition and Consumer Commission (**ACCC**) to develop an economic benchmarking model (the **Model**) to illustrate the potential application of economic benchmarking. The RDB has also been asked to provide an accompanying technical report (the **Report**) that sets out principles in relation to how economic benchmarking results could be used to assess forecast expenditure in regulatory determinations.

The purpose of the Model is to demonstrate how:

- the mechanics of economic benchmarking methods outlined in the issues paper released by the AER (AER, 2012) may work;
- economic benchmarking methods may be applied in the review of expenditure forecasts;
- various efficiency and productivity concepts, including measures of technical efficiency, scale efficiency, and allocative efficiency, are relevant to the review of expenditure forecasts; and
- efficiency adjustments may be made to NSPs' expenditure forecasts including how efficiency gains that are attainable in the short run and efficiency gains that can only be attained gradually over the long run may be managed.

This Report also sets out high-level principles regarding:

- how efficiency scores derived from economic benchmarking analysis could be used to guide assessment of whether adjustments to forecast operating expenditure (opex) and capital expenditure (capex) should be made;
- how different efficiency scores under the holistic approach might be used to calculate adjustments to forecast capex and opex; and
- how the use of efficiency scores under the holistic approach for adjusting forecast capex and opex may change over time (for example, as the quality and quantity of data held by the AER improve).

[1] The Regulatory Development Branch provides specialist advisory services in economics and finance to the ACCC and the AER on regulatory matters.

2. *Scope*

This Report provides an illustration of the possible regulatory application of economic benchmarking methods to the assessment of expenditure forecasts. In practice, economic benchmarking is likely to be only one of a suite of techniques used to arrive at decisions on expenditure forecasts.

Economic benchmarking compares the current performance of an NSP to its own performance over time and to the performance of other NSPs. Economic benchmarking methods provide a 'top-down' measure of the relative performance of NSPs using a number of measures of performance, including assessing an NSP's relative levels of: cost efficiency; technical efficiency; allocative efficiency and scale efficiency.

Technical efficiency occurs when an NSP produces a given quantity of output with the minimum possible quantity of inputs. Allocative efficiency requires an NSP to use input quantities in the same proportions that would minimise costs, given the input prices it faces. An NSP is cost efficient if it produces its output at minimum cost. An NSP that is technically and allocatively efficient is cost efficient. Finally, an NSP is scale efficient if it operates at an optimal size (AER 2012, pp. 53-54). Productivity change measures changes in an NSP's cost efficiency.

It is envisaged that economic benchmarking could be initially be used for three principal regulatory uses (Economic Insights 2013a):

- 'first pass' assessment at an early stage of the regulatory determination process designed to identify areas of the expenditure forecasts that warrant further investigation (AER 2012, pp. 32-34);
- reviewing the relative efficiency of historical NSP expenditure and whether base-year expenditure can be accepted as an efficient base and trended forward or whether it may be necessary to make adjustments to base-year expenditure to remove observed inefficiencies (this could also be implemented using a 'glide path'); and
- quantifying the feasible rate of efficiency and productivity growth that the NSP can be expected to achieve over the next regulatory period. This would include separately examining costs that are flexible in the short run (e.g., opex) and costs that may be progressively adjusted over the longer term (e.g., capital inputs). The consideration of scale efficiency change may also be relevant.

In order to illustrate these three principal uses in expenditure forecast assessment, the Model employs three of the four economic cost benchmarking methods identified in AER (2012):

a) Multilateral Total Factor Productivity Analysis (**MTFP**). MTFP is an index-number-based method that calculates and compares NSPs' productivity levels and growth rates. The estimates can provide a measure of overall cost efficiency of an NSP.

b) Data Envelopment Analysis (**DEA**). DEA uses linear programming methods to construct an industry efficient frontier, to which relative efficiency performance of individual NSPs is compared. This method provides estimates of cost efficiency which can be decomposed into technical efficiency and allocative efficiency. The results can be used to cross-check MTFP index results and examine possible sources of relative cost inefficiency.

c) Econometric methods. Econometric cost modelling estimates an industry-average benchmark cost function. The results from the estimation of an opex cost function may be used to assess the opex efficiencies, as well as the opex partial productivity growth rates of NSPs.

In the Model, MTFP and DEA methods have been applied to the assessment of total costs. This demonstrates how 'total cost' assessment may be used in the regulatory context as a 'first pass' test. The results can also provide useful information regarding the possible productivity and efficiency improvements that the NSP may achieve in the longer term. The opex cost function application provides an example of its potential uses both in assessing the base-year efficient opex and in quantifying the opex partial productivity growth rate under the opex rate-of-change roll-forward formula. The opex rate-of-change formula rolls base-year efficient opex forward by the percentage change in opex input prices plus the percentage change in output less the percentage change in opex partial productivity. Step changes in opex would be assessed separately.

These three methods, namely MTFP, DEA and the Econometric method, have been selected because they are relatively less data-intensive compared to applications such as Stochastic Frontier Analysis (**SFA**) using sufficiently flexible functional forms. Of the three methods considered MTFP requires the least number of observations to implement.

Data for thirteen hypothetical businesses over six years are analysed to illustrate potential regulatory applications. The sample consists of Network Service Providers (**NSPs**) operating with different combination of inputs and outputs over time. A detailed description of the dataset is presented in Appendix 1.

It is important to note that the Model does not test for, nor identify, a preferred model specification, and sensitivity analysis with respect to alternative input-output specifications has not been undertaken. These are tasks more appropriately undertaken once a robust NSP database is established. The Model also does not specifically consider the appropriate benchmarks to use to compare NSPs' efficiency to. In each case, either frontier business(es) or industry-average businesses have been selected as the appropriate benchmark, and there is no testing for alternative benchmarks that could be adopted.

A spreadsheet titled 'Economic Benchmarking Model' has been constructed to provide a detailed exposition of the Model. A description of the spreadsheet is presented in Appendix 2.

Section 3 of this Report illustrates the use to economic benchmarking of total cost using multilateral TFP and DEA methods for potential 'first pass' expenditure forecast assessments. That is, the two methods are used to estimate the overall cost efficiency performance of NSPs, and their implications for NSP expenditure forecasts are considered**.**

Section 4 of this Report illustrates econometric modelling of the opex cost function and its use in assessing base-year opex efficiency and forming opex forecasts using the rate-of-change roll-forward formula.

Full sets of benchmarking results are presented in Appendix 3.

Principles for using economic benchmarking results are presented in section 5 and conclusions are presented in the final section.

3. First-Pass Total Cost Assessment Using MTFP and DEA

As discussed, in this section, total cost assessment using MTFP and DEA is presented to provide a 'first-pass' assessment of an NSP's expenditure proposal. This application can potentially be used to consider whether an NSP's current performance and expenditure forecasts appear efficient and, hence, whether the use of a revealed costs approach may be appropriate. If the NSP's current performance and expenditure forecasts appear inefficient then a more intensive review including the use of detailed engineering analysis may be required.

3.1. MTFP

3.1.1. Method

TFP measures aggregate output produced per unit of all inputs used. Following Caves, Christensen and Diewert (1982), the multilateral Tornqvist index is used to compare productivity levels for a panel of thirteen NSPs over six years. The multilateral TFP (MTFP) index (in logarithmic form) is calculated as:

$$\begin{aligned}\ln(MTFP_{st}^{T*}) &= \ln(Y_{st}^{T*}) - \ln(X_{st}^{T*}) \\ &= \left[\sum_{i=1}^{N}\left(\frac{\omega_{it}+\overline{\omega}_i}{2}\right)(\ln y_{it} - \overline{\ln y_i}) - \sum_{i=1}^{N}\left(\frac{\omega_{is}+\overline{\omega}_i}{2}\right)(\ln y_{is} - \overline{\ln y_i})\right] \qquad (1) \\ &\quad - \left[\sum_{j=1}^{M}\left(\frac{\omega_{jt}+\overline{\omega}_j}{2}\right)(\ln x_{jt} - \overline{\ln x_j}) - \sum_{j=1}^{M}\left(\frac{\omega_{js}+\overline{\omega}_j}{2}\right)(\ln x_{js} - \overline{\ln x_j})\right]\end{aligned}$$

where Y_{st}^{T*} and X_{st}^{T*} are the multilateral Tornqvist quantity indexes for outputs and inputs respectively, ω refers to the revenue or cost share, and the bar refers to the sample average of the relevant variable. The method compares two businesses (*t* and *s*) indirectly by comparing them each to the hypothetical average business in the sample. This index number form satisfies the important property of transitivity, which is required for consistently comparing productivity levels within panel data (see Lawrence, Swan and Zeitsch 1991 for a detailed explanation).

One of the strengths of employing this method in a regulatory context is that the MTFP index provides an ideal way to benchmark productivity performance as it enables productivity levels as well as productivity growth rates to be compared across businesses. Productivity differentials (changes) measured by the MTFP index indicate cost efficiency differences (changes) given the prevailing technology and input prices. This is explained by Zeitsch and Lawrence (1996), who compared cost efficiency results obtained using MTFP index and DEA methods. In this context, cost efficiency occurs where an NSP produces its outputs at minimum cost. This requires that the given level of output be produced from the minimum combination of input quantities and the cost of those inputs must be the lowest for the given level of output produced. That is, the notion of cost efficiency encompasses a point where an NSP is both technically and allocatively efficient.

The MTFP indices identify productivity differentials among NSPs at one point in time, as well as productivity changes over time for each NSP and for the industry as a whole. However, the index-number-based TFP method does not provide a decomposition of productivity changes or differentials into its sources.

The efficiency and productivity performance of individual NSPs can be influenced by several factors including technical change over time, scale of operations and the operating environment. For meaningful comparison using benchmarking, it is important to consider and, where necessary, control for business environment differences that are out of management control but have a material impact on productivity and efficiency performance. For illustrative purposes, the synthetic data constructed for use in the Model reflects NSPs operating in similar operating environment conditions. As a result, in the Model we do not adjust the raw MTFP or cost efficiency results for operating environment factors as, by construction, the NSPs all face broadly similar operating environment conditions. However, in practice, where more diverse NSPs might be included for economic benchmarking it would be necessary to explicitly model the impact of key operating environment factors that may affect NSP performance.

One way to model the impact of operating environment factors is to run two-stage regression analysis of raw MTFP results, as recommended by Coelli, Rao, O'Donnell and Battese (2005, pp. 194-95). For example, in an international benchmarking study of postal service productivity, Economic Insights (2009a) adjusted TFP results for country-specific differences in relation to mail density and customer density. The adjusted MTFP results were produced using two steps:

- First, econometric analysis is performed to examine the relationship between raw MTFP results and the most significant operating environment factors; and
- Second, adjusted MTFP results are derived after adjusting for those operating environment effects based on the econometric results. This can be done by adding the sum of the product of each estimated coefficient and the difference between the sample-average and the actual value of the relevant explanatory variable to the raw MTFP.

3.1.2. Results

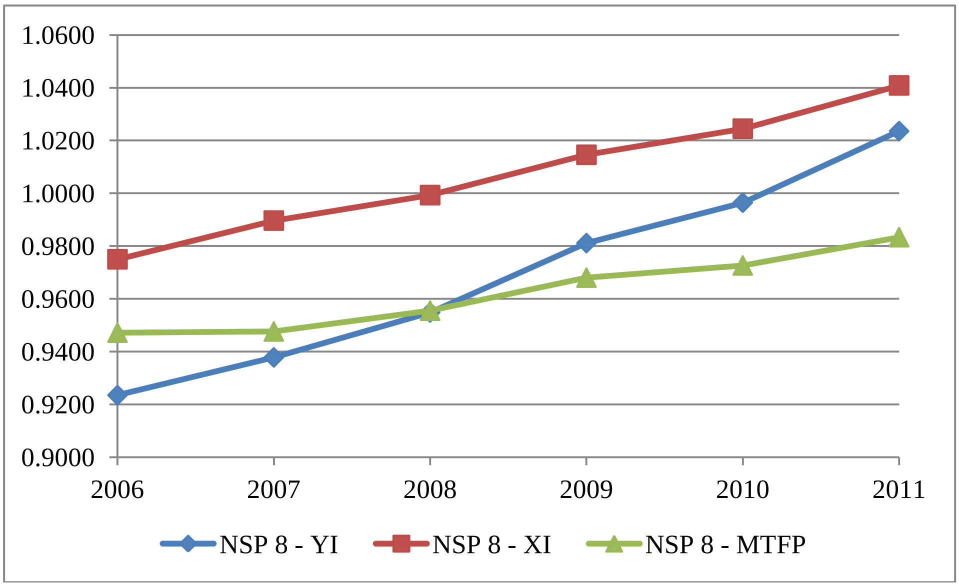
The model presented for the MTFP analysis includes two illustrative outputs and four illustrative inputs for 13 NSPs over six years, labeled 2006 to 2011. The outputs are labeled Y_1 and Y_2 and could, for example, be customers and peak demand. Similarly, the four inputs are labeled X_1–X_4 and could, for example, be opex, overhead line length, underground cable length and transformer capacity.

For convenience, the MTFP of each business is presented relative to the MTFP of the first observation (i.e., NSP 1 in year 2006), which is given a value of one. The results are invariant to which observation is chosen as the reference point. MTFP is calculated in accordance with equation (1) above in the 'TFP Index' worksheet.

A 'TFP Analysis' worksheet has also been constructed to present further analysis of productivity performance of individual NSPs over time. The worksheet contains graphical and tabulated analysis of the raw MTFP results. The full results by NSP and year are presented in Table A3.1 in Appendix 3.

For example, aggregate output quantity, input quantity and TFP indexes are presented for NSP 8 in Figure 1 below. During the sample period 2006 to 2011, aggregate output quantity grew strongly from 0.924 to 1.024. The average annual growth rate (calculated as geometric mean) for outputs is 2.08 per cent. During the same period, aggregate input quantity grew less strongly, at an annual rate of 1.32 per cent. The residual TFP grew by 0.75 per cent per annum. This resulted in a modest improvement of MTFP (relative to NSP 1 in year 2006) from 0.947 to 0.983.

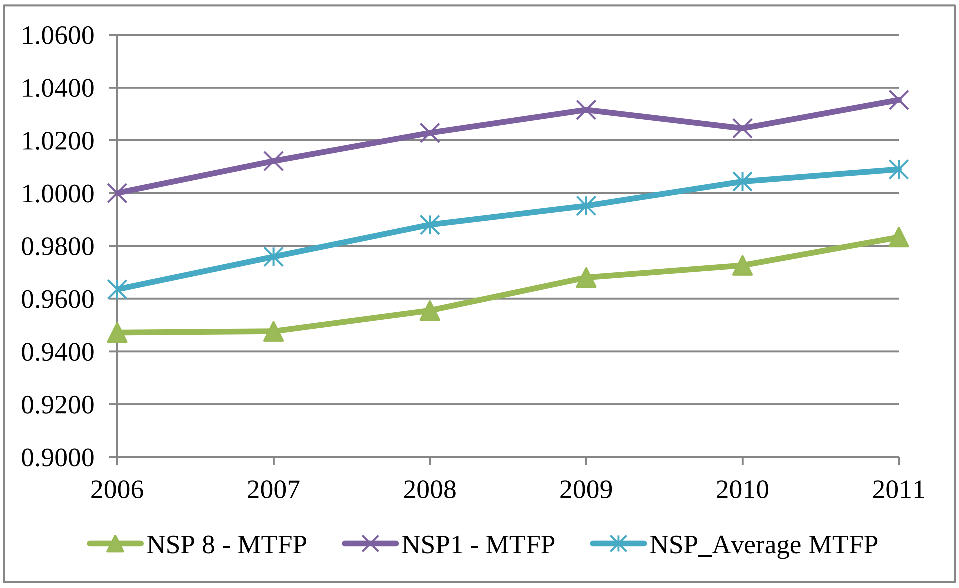
Figure 1: Aggregate Output, Input and TFP Indexes for NSP 8



Notes: YI denotes output quantity index and XI denotes input quantity index.

When compared with the frontier NSP (i.e., NSP 1 in this sample) or the sample average, NSP 8 is found to be relatively inefficient in terms of MTFP level (see Figure 2 below). Its average annual productivity growth rate of 0.75 per cent is similar to that of the frontier NSP (at 0.70), but smaller than the average growth rate achieved by the group at 0.93 per cent. In 2006, NSP 8 ranked last in the group. Despite modest productivity improvement over time, it continued to be the least productive NSP in the group for all the sample years.

Figure 2: TFP Performance of NSP 8 Relative to Frontier and Average NSPs



The regulatory implications of NSP 8's poor efficiency performance will be discussed in section 3.3.

3.2. DEA

3.2.1. Method

DEA is a non-parametric approach that uses linear programming method to evaluate the performance of firms across an industry (Charnes, Cooper and Rhodes, 1978; Seiford and Thrall, 1990; Lovell, 1993).

DEA analysis can provide a decomposition of cost efficiency into sources such as technical efficiency and allocative efficiency. The results can be used for two purposes:

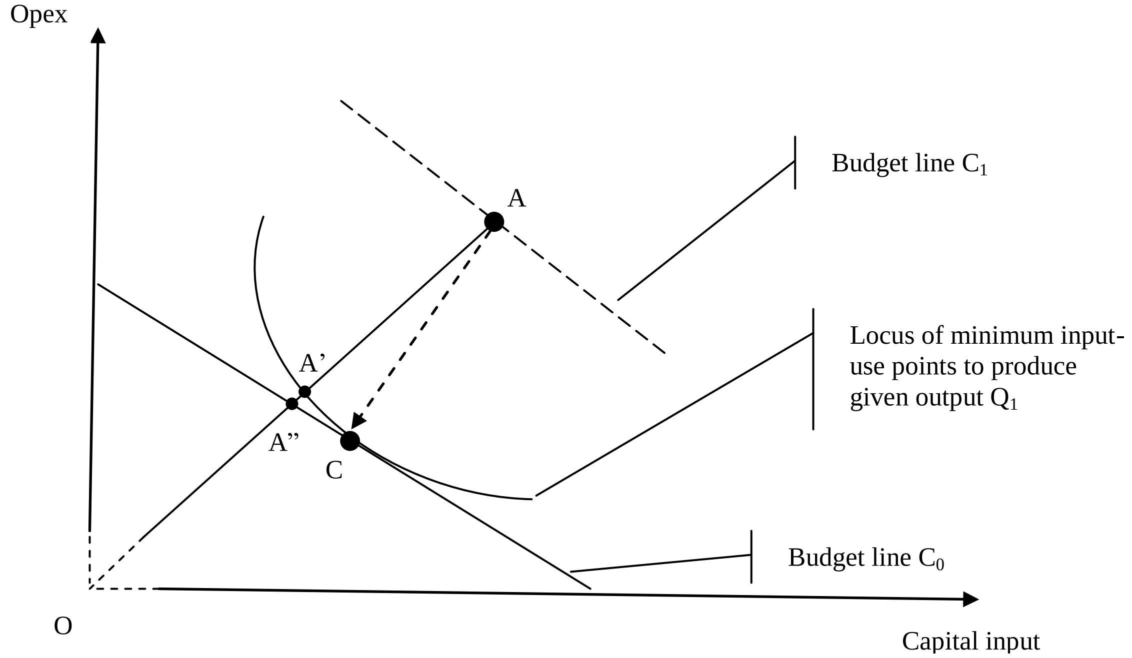
- First, to cross-check the MTFP index results to see whether the two sets of cost efficiency results are consistent; and
- Second, to examine the sources of cost inefficiency.

Following Farrell (1957), the concepts of technical efficiency, allocative and cost efficiency are depicted diagrammatically in a two-input and one-output model in Figure 3 below. Figure 3 is drawn with one isoquant curve Q_1 (representing the minimum combinations of inputs required to produce the same level of output) and two isocost lines C_0 and C_1 (each representing the various input combinations that have the same total cost), where all sampled NSPs are assumed to produce the given level of output using opex and capital inputs.

As shown in the diagram, any observation lying on the isoquant curve can be regarded to be technically efficient. Such an NSP is producing the given level of output using the minimum possible quantity of inputs. A tangent point between an isocost line and an isoquant curve represents the optimum from a cost-minimising point of view. An NSP operating at such a point is using the appropriate combination of inputs to produce the given level of output at least cost, given the technology in place and the input prices it faces.

However, for the NSP considered (point *A*) which is located further away from the isoquant in the northeast direction, it is not technically efficient or cost efficient. Point *A'* is its technically efficient benchmark, indicating that the NSP considered could improve its technical efficiency performance by reducing its inputs proportionately by the ratio of A'A/OA. Point *C* is its cost efficient benchmark, indicating that the NSP considered could potentially reduce its costs by the proportion of A"A/OA.

Figure 3: Illustration of Efficiency Concepts



To recap, as illustrated in Figure 3, efficiency performance of an NSP can be measured by:

- technical efficiency, which is one minus the proportion by which inputs used could be reduced to produce the same output as an NSP operating on the efficient frontier (i.e., OA'/OA);
- cost efficiency, which is the ratio of costs that would be faced by an NSP using the cost-minimising combination and level of inputs relative to its actual costs (OA"/OA); and
- input-mix allocative inefficiency, which is the ratio of costs of an NSP that employs a cost-minimising level of inputs, relative to the costs incurred if a technically efficient level of inputs is used but in the same original proportions (OA"/OA'). It can be calculated residually as the ratio of cost efficiency to technical efficiency.

3.2.2. Results

Using the same input-output specification as used in section 3.1 for the MTFP method, DEA has been applied to the estimation of cost efficiency,[2] and its decomposition into technical efficiency and allocative efficiency.[3] DEA cost efficiency and technical efficiency results are calculated in the worksheets 'DEA_CE Cal' and "DEA_TE Cal' respectively. Further analysis of DEA results (including the computation of allocative efficiency) is presented in the worksheet 'DEA Analysis'. The full sets of DEA efficiency results are presented in Tables A3.2 to A3.4 in Appendix 3.

For cross-checking purposes, the raw MTFP indexes are converted into MTFP scores relative to the maximum value of MTFP in the sample (i.e., the results are rescaled so that MTFP for NSP 1 in year 2011 equals one). This enables the MTFP results to be compared with the DEA results. The two sets of cost efficiency results are similar, with a Pearson Product

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[2] DEA has been performed within the Spreadsheet Model, using Excel Solver calculations which have been automated with a written macro.

[3] The model is input-oriented and assumes a constant returns-to-scale technology.

Moment correlation coefficient of 0.961. There are similar mean efficiency scores (0.962 versus 0.956) and the results have a similar spread (0.22 versus 0.21).

The DEA decomposition shows that the major source of cost inefficiency is allocative inefficiency. The mean technical efficiency for the sample is 0.991. The Model assumes that:

- prices paid for opex by NSPs are the same at a particular point in time, but the prices change at the rate of the opex price deflator; and
- prices paid for capital inputs may differ across the businesses and over time. Further, the annual capital input prices are indirectly derived based on the assumption that capital cost is 12.5 per cent of the value of regulatory asset base (RAB). This is consistent with earlier studies for New Zealand electricity distribution businesses; for example, Economic Insights (2009b, p. 15) based on 8.5 per cent WACC and 4 per cent depreciation (i.e., 25 years remaining life). Assumptions regarding cost shares also apply (See the calculations in the Worksheets 'Gen Data' and 'TFP Index').

For the given input prices, the NSPs are found to have average allocative efficiency of 0.970. This implies that, on average, the group could reduce costs by 3 per cent by producing with the cost-minimising level of inputs for the prevailing technology and input prices.

The DEA cost efficiency results are found to be highly consistent with the MTFP results. The DEA results also provide useful information regarding the sources of inefficiency. To simplify the illustration of regulatory applications (see below), the MTFP results will be relied on rather than having regard to both sets of cost efficiency results from MTFP and DEA methods. In regulatory practice, results from alternative methods may be considered jointly.

3.3.Regulatory application of 'total cost' benchmarking results

Economic benchmarking of total costs can be used to provide a high-level review of the relative efficiency of historical NSP expenditure and trend efficiency and productivity growth of an NSP, or of NSPs as a group. Calculating the path of total costs using an aggregate rate-of-cost-escalation formula incorporating a rate of productivity growth can also provide a reference total cost forecast against which to compare the NSP's forecast expenditure under the Building Block Model (BBM). The productivity growth rate captures the elimination of cost inefficiencies over a period sufficiently long to allow adjustment and the pursuit of further productivity improvements over time.

As proposed by the AER (2012, pp. 32-34), economic benchmarking of total costs may be used primarily in the 'first pass' test of NSPs' expenditure forecasts. That is, benchmarking methods may be used at an early stage of the regulatory determination process to assess the overall cost efficiency of individual NSPs relative to each other and their own trend over time, in order to identify areas of an NSP's expenditure forecasts that may warrant further investigation.

Within the 'first pass' test, where economic benchmarking results suggest that an NSP is relatively inefficient in relation to historical expenditure, and its proposed forecast is materially higher than what is required by an NSP with strong incentives to operate efficiently, further investigation into the proposed expenditure may be required. If this finding is supported by other high-level assessment tools such as category analysis – a regulatory tool that attempts to identify cost 'drivers' that are thought to influence each category of expenditure – then the AER may opt to undertake a more intensive review using detailed engineering and other assessments.

As illustrated in the Model, economic benchmarking using, for example, MTFP and DEA methods, can be employed at an early stage of the regulatory determination as one component of the suite of 'first pass' assessment methods to review the efficiency of an NSP's total costs. For simplicity, only the MTFP results are used to illustrate the regulatory application.

3.3.1. Example illustration in the worksheet 'Reg App TC'

An example of the potential regulatory use of 'total cost' benchmarking results is provided in the worksheet 'Reg App TC'. It compares the hypothetical NSPs' future cost proposals calculated under the BBM with the cost forecasts using economic benchmarking.

Under the BBM, the forecast annual total costs are the summation of three building blocks, namely opex, return of capital, and return on capital. In support of its expenditure proposal, an NSP forecasts annual opex and capex requirements, as well as the Weighted Average Cost of Capital (WACC), for the next regulatory period. These forecasts are used as inputs into the BBM for the computation of the annual total cost requirements over the forecast regulatory period. The net present value of annual total costs over the period then determines the total revenue requirement.

In comparison, an estimate of the total costs of an NSP over the forecast regulatory period can be formed by the AER using the economic benchmarking approach. Under the latter approach, future total costs required by each NSP are derived by adjusting the NSP's actual total costs in the base year annually for the following:[4]

- overall output growth; and
- overall input-price change (which is a weighted average of opex price change and capital input price change), net of potential productivity and efficiency change (the scope of which depends on many sources such as the NSP's existing cost inefficiency level, technical change and potential scale efficiency change).

This aggregate rate-of-change formula is analogous to the regulatory application of a 'base-step-trend' analysis to opex assessment (see sections 4.3 and 4.4 for details). The difference is that the 'total cost' application considers all inputs, including capital input, and thus annual total cost escalation takes into account the overall input-price change net of total factor productivity growth and overall cost efficiency change.

For expositional purposes, the Model assumes that the annual rate of productivity and efficiency growth over the forecast regulatory period is the sum of two components:

- an efficiency improvement factor – The NSP-specific overall cost inefficiency is assumed to be gradually removed over the next 20 years; and
- a productivity growth factor – The observed industry-average productivity change is considered as a good indicator of future productivity change for each NSP.

Together, the benchmarking results provide an NSP-specific annual rate of change for total costs over the forecast regulatory period. That is, the annual rate of cost escalation is calculated as:

$$\Delta TC = \Delta Output\ \ quantity + \Delta Input\ \ \Pr ice - \Delta \Pr oductivty\ \ and\ \ Efficiency \quad (2)$$

[4] Additional adjustments may be made for non-recurrent cost arising from 'step changes' due to changes in regulatory requirements or external operating environment.

where the growth rates of output quantity, input prices, and productivity and efficiency can be gauged on the basis of past trend.[5]

This is illustrated in the 'Reg App TC' worksheet, which calculates NSP-specific annual cost-escalation rates that incorporate potential cost-efficiency gains and productivity gains. It assumes that the annual productivity and efficiency change is the sum of one-twentieth of the NSP's base-year cost inefficiency (that is, observed inefficiencies could be potentially eliminated over a 20 year timeframe) and annual industry-average productivity gains. It is important to note that the potential productivity and efficiency changes that can be achieved by each NSP over the forecast regulatory period are chosen for illustrative purposes only in the example and are likely to require further refinement. For example, the time period required to remove the inefficiencies may not necessarily be 20 years.[6] The potential productivity and efficiency change for each NSP may be based on the NSP's historical performance in this regard.

Under the economic-benchmarking approach, the reference annual total-cost forecasts for each NSP over the next regulatory period are formed by adjusting the NSP's base-year actual total costs by the annual rate-of-cost-escalation formula. The net present value of annual total costs over the period can then be formed to facilitate comparisons.

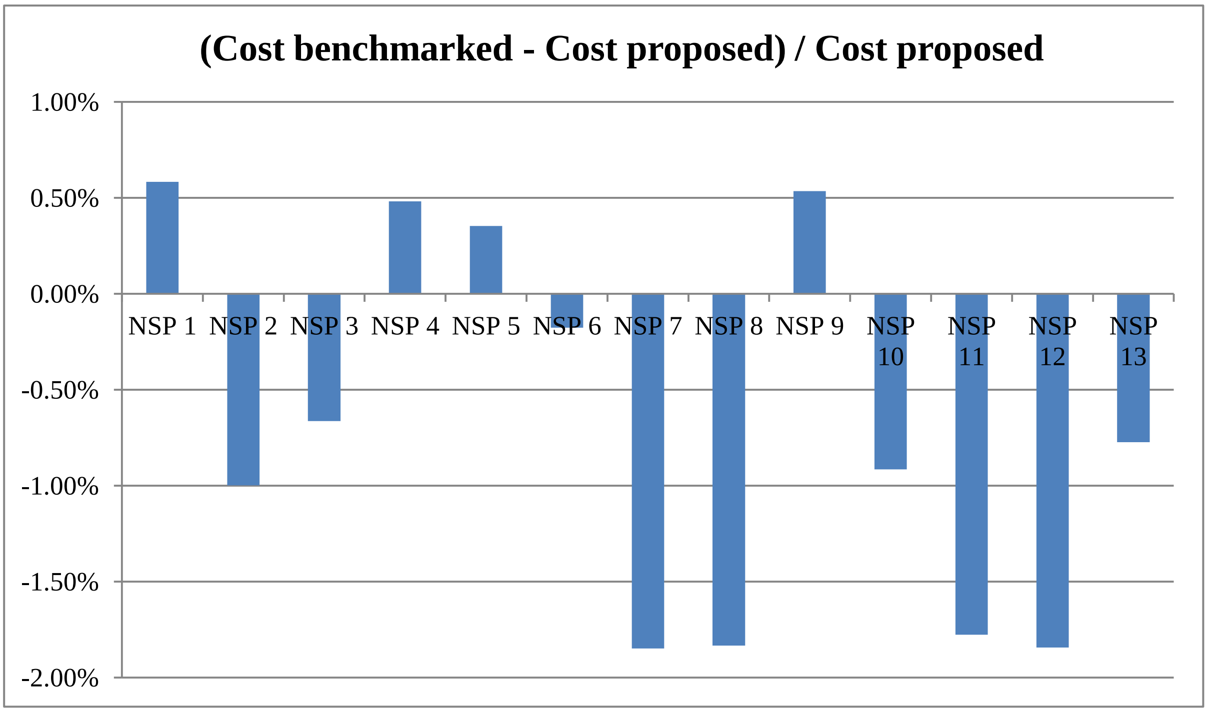
The two sets of forecast costs – one proposed by the NSP based on its forecasts and modelling, and the other formed by the AER using an economic-benchmarking approach – would then be compared to indentify sources of discrepancies.

Figure 4 summarises the total cost benchmarking outcomes for individual NSPs. Total costs proposed by some NSPs (i.e., NSP 1, 4, 5 and 9) are lower than reference total costs suggested under economic benchmarking. For other NSPs, substantial potential cost reduction in the range of 0.66 per cent and 1.85 per cent of total costs proposed has been identified under economic benchmarking.

[5] Information about expected future changes to output and input prices is required. It may be the case that output forecasts can be obtained by assuming the same rate of historical change. For expected future input prices, ABS price data on labour, material and capital inputs are required.

[6] In the longer term inputs are not fixed. NSPs may have a greater flexibility to adjust levels of inputs into their production. This involves considerations of system asset retirement, replacement and augmentation needs of the network.

Figure 4: Total Cost Benchmarking Outcomes for the 13 NSPs



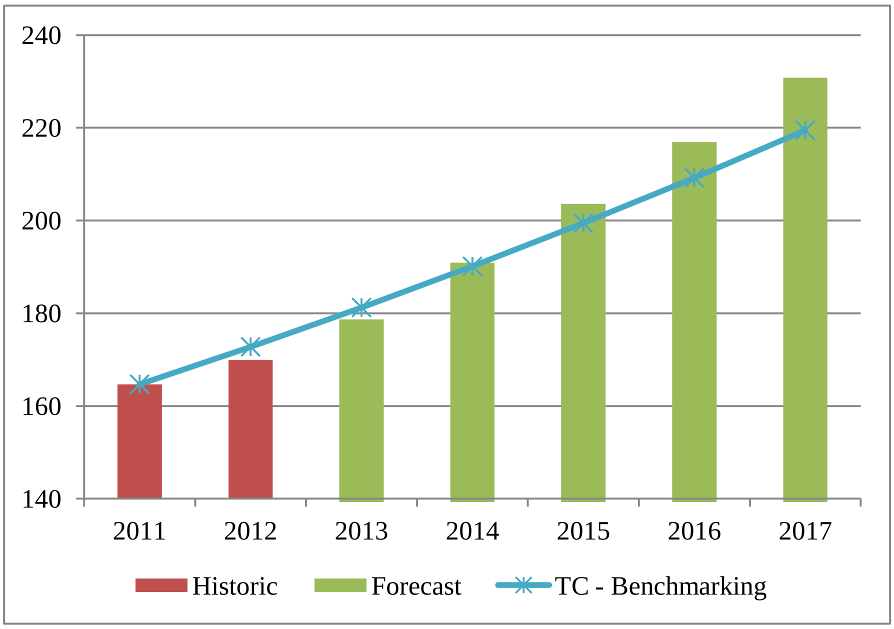
3.3.2. ‘First pass’ test

Under the proposed ‘first pass’ expenditure assessment, an NSP’s proposed expenditure will be reviewed during the early stages of the regulatory determination process by using a suite of assessment tools such as category analysis and economic benchmarking.

As illustrated in section 3.3.1, the economic benchmarking results can be used to form a reference set of cost forecasts, which accounts for expected future productivity and efficiency improvements offsetting higher costs resulting from higher output quantities and input prices. Where economic-benchmarking results suggest that an NSP is relatively efficient in relation to historical expenditure, and its proposed forecast costs are materially lower than the reference forecasts (e.g., NSP 1 in Figure 4), the determination for that NSP may be fast-tracked (provided there is supporting evidence for this course of action from category analysis). On the other hand, where economic-benchmarking results suggest that an NSP is relatively inefficient in relation to historical expenditure, and its proposed forecast costs are materially higher than what are required by a service provider with strong incentives to improve productivity and efficiency over time, detailed investigation into the proposed expenditure forecasts may be required.

Using NSP 8 for example, Figure 5 presents annual total cost estimates and forecasts proposed by the NSP (in column) and reference annual total costs established under the economic-benchmarking approach (in dotted line). For four years of the forecast regulatory period (2014 to 2017), the NSP has proposed higher total costs than those suggested by economic benchmarking. In a net present value sense, total costs proposed by the NSP for the forecast regulatory period are higher than the benchmarked total costs by $14.485 million (in 2012 dollar value). The discrepancy in forecast costs may be due to different views formed by the NSP and the AER in relation to demand outlook, input requirements and potential scope for productivity and efficiency improvements. As the least productive network in the sample, NSP 8 is allocated the highest productivity and efficiency growth rate of 1.18 per cent per annum in forming the reference cost forecasts.

Figure 5: Comparing Total Cost Forecasts



If this finding is supported by other high-level assessment tools such as category analysis, then the AER may make an overall judgment on the efficiency of the proposed expenditure. It may opt to undertake a more intensive review using detailed engineering and other assessments to examine areas of concern that have been identified by the high-level assessment.

It should be noted that results from the total cost benchmarking would not be used in an entirely mechanical way. Economic benchmarking of total costs would be used in combination with other assessment tools for reviewing the efficiency of total historic costs of NSPs, and would indicate the trend efficiency and productivity growth the industry or a group of comparable NSPs may experience.

4. Econometric Modelling of Opex Cost Function

Economic benchmarking of opex can play an important role in reviewing the forecast opex of NSPs. The opex cost modelling results can be used for assessing the base-year efficient opex, as well as gauging the opex partial productivity growth rate. The results indicate whether base-year actual opex can reasonably be trended forward and inform the calculation of the trend opex growth rate. Depending on the opex efficiency results, the benchmarking analysis may suggest that base-year opex requires adjustment to remove observed inefficiencies. The results will be used in conjunction with other assessment tools for opex assessment.

4.1. Method

An econometric model of a relatively simple opex cost function has been estimated using the same dataset for the 13 hypothetical NSPs over six years. As a short-run cost function, it is modeled as a function of the amounts of outputs supplied (Y_1 *and* Y_2), opex input price (w_{opex}), capital input quantity (X_k), time trend (TT) and other characteristics of the NSPs (Z_1).

Capital input is assumed to be beyond management control in the short run and is therefore treated as a fixed input in the econometric model. A log-linear function has been employed:

$$\begin{aligned}\ln Opex &= b_0 + b_1 \ln Y_1 + b_2 \ln Y_2 + 0.5 b_{11} (\ln Y_1)^2 + 0.5 b_{22} (\ln Y_2)^2 + \ln wopex \\ &+ b_3 \ln X_k + b_4 TT + b_5 \ln Z_1\end{aligned} \tag{3}$$

The opex input price enters the operating cost function with a coefficient of one in this instance to ensure homogeneity of degree one in prices (i.e., holding other things constant, cost increases by the same proportion as the input price change – a key property of cost function). Following Economic Insights (2012), the estimated cost function parameters have been used to derive the level of opex required by efficient NSPs to deliver services in specific environments and using industry-average technology. For each NSP, the predicted opex is compared with actual opex to measure opex efficiency. Where the ratio of an NSP's predicted costs is greater than actual costs, the measure of opex efficiency is larger than 1. In this case, the NSP has performed better than sample-average efficiency (i.e., opex efficiency = 1) after allowing for the operating environment effects. Where the ratio of an NSP's predicted costs are less than actual costs, the measure of opex efficiency is less than 1. The NSP is relatively inefficient after taking into account the operating environment effects. One minus the efficiency score shows the proportion of actual opex that could be reduced by an inefficient NSP to operate as efficiently as the sample average.

Opex partial productivity growth rates have also been derived using the parameter estimates from the opex cost function model. Largely following Economic Insights (2012, p. 18), the growth rate of the opex partial productivity index ($P\dot{F}P_{Opex}$) is calculated as:

$$P\dot{F}P_{\mathrm{Opex}} = (1 - \textstyle\sum_i \varepsilon_{Y_i}) \cdot \dot{Y}^{\varepsilon} - \varepsilon_{X_k} \cdot \dot{X}_k - \varepsilon_{Z_1} \cdot \dot{Z}_1 - \dot{g} \tag{4}$$

Where:

a dot over a variable represents the variable's growth rate;

$\dot{Y}^{\varepsilon}$ is the growth rate of an output quantity index where the weights for each output are the cost elasticity divide by the sum of the output cost elasticities;

$\sum_i \varepsilon_{Y_i}$ is the sum of the elasticities of output i (i = 1, 2) with respect to opex cost;

$\varepsilon_{Z_1} \cdot \dot{Z}_1$ is the growth rate of the operating environment factor multiplied by its opex elasticity;

$\varepsilon_{X_k} \cdot \dot{X}_k$ is the product of capital quantity by its opex elasticities; and

$\dot{g}$ is the shift in the cost function over time.

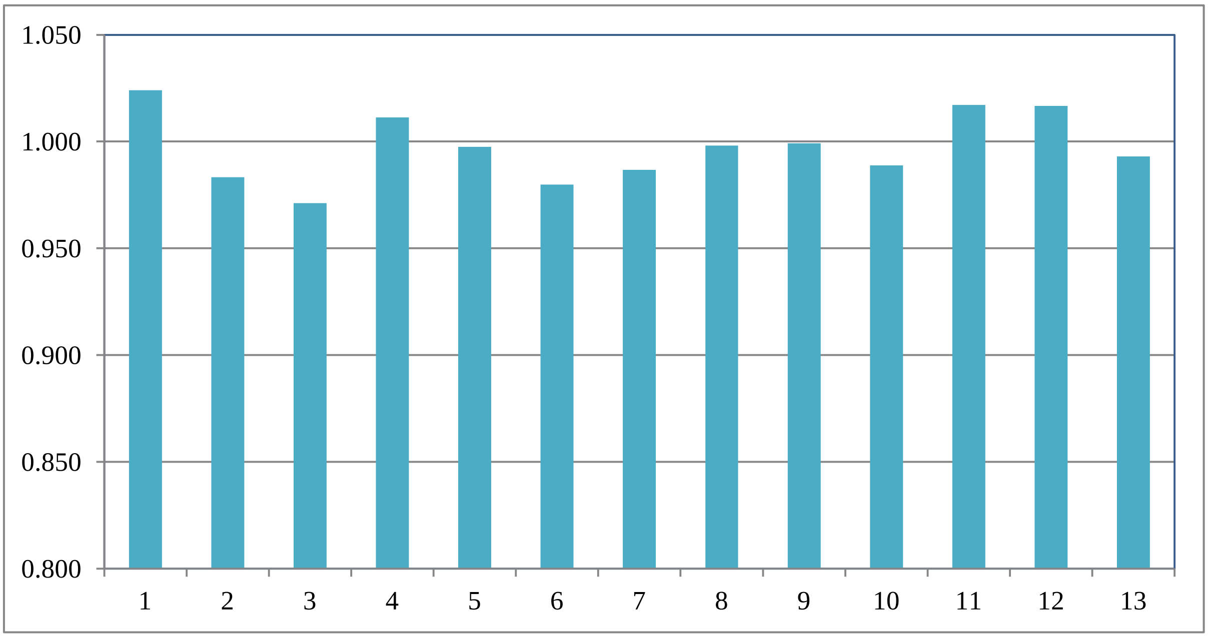
From equation (4), the measure of opex partial productivity change captures a number of factors, including: industry-specific technical change ($\dot{g}$ term); NSP-specific returns-to-scale effect ($\sum_i \varepsilon_{Y_i} \cdot \dot{Y}^{\varepsilon}$ term), and NSP-specific business condition change effect (incorporating $\varepsilon_{X_k} \cdot \dot{X}_k$ and $\varepsilon_{Z_1} \cdot \dot{Z}_1$). The estimated operating cost function parameters are combined with forecasts of future output growth, non-opex input growth and changes in operating environment conditions to form forecasts of future opex partial productivity growth.

4.2. Results

The regression results for the opex cost function are presented in Table A3.5 in Appendix 3. Based on the regression results, the opex efficiency and opex partial productivity change for each of the sample NSPs are calculated in worksheets 'Opex Efficiency' and 'Opex Productivity' respectively.

The opex efficiency results for the NSPs in 2011 are presented in Figure 6 below. Four of the 13 NSPs (i.e., NSP 1, 4, 11, and 12) are found to have opex efficiency above one, indicating that they operated efficiently in the year (relative to the sample-average benchmark). The remaining NSPs were, to some extent, relatively inefficient compared to the sample-average efficiency benchmark. If an NSP's base year opex is found to be inefficient by a sufficiently wide margin and other assessment tools such as category analysis also indicated a degree of inefficiency, then adjustments to base-year opex (by way of a one-off change or, alternatively, by glide path) may be appropriate.[7] The full set of results is presented in Table A3.6 in Appendix 3.

Figure 6: Opex Efficiency of NSPs (2011)



In Table 1 below, the estimated operating cost function parameters are also combined with forecasts of output and capital input levels to form forecasts of future opex partial productivity growth using equation (4). For expositional purposes, in the Model historical rates of change for technical progress, output growth, and business conditions (including capital input changes) observed for the sample period 2006 to 2011 are assumed to prevail in the next regulatory period. In regulatory practice, AER-agreed forecast values of these variables would be used. The opex partial productivity growth rates (as the sum of technical change, returns-to-scale effect and business condition change effect) are forecast to be between 2.34 per cent and 2.70 per cent per annum for the thirteen NSPs over the next regulatory period.

[7] In empirical analysis, a confidence interval may be calculated around sample-average efficiency opex with those NSPs whose inefficiency is outside the confidence interval being targeted for consideration of base-year opex adjustment.

Table 1: Opex Partial Productivity Growth Rate Forecasts

Model's estimated cost elasticities						**Output weights**							
Y_1	0.1965					39.44%							
Y_2	0.3017					60.56%							
X_k	0.1834												
Z_1	0.3568												
TT	-0.0346												
NSP's historic cost driver growth rates (2006 – 2011)													
	NSP1	*NSP2*	*NSP3*	*NSP4*	*NSP5*	*NSP6*	*NSP7*	*NSP8*	*NSP9*	*NSP10*	*NSP11*	*NSP12*	*NSP13*
Y_1	1.73%	1.84%	2.09%	2.25%	2.26%	2.34%	1.95%	2.21%	2.30%	2.01%	2.52%	2.41%	2.32%
Y_2	3.06%	2.98%	2.64%	2.57%	2.79%	2.24%	2.10%	1.95%	2.11%	2.01%	1.58%	1.70%	1.41%
Output Growth	2.53%	2.53%	2.42%	2.45%	2.58%	2.28%	2.04%	2.05%	2.19%	2.01%	1.95%	1.98%	1.77%
X_k	0.70%	0.82%	0.79%	0.62%	0.80%	1.08%	0.86%	1.13%	1.06%	0.86%	0.98%	1.23%	0.97%
Z_1	0.0610	0.0593	0.0537	0.0592	0.0535	0.0523	0.0556	0.0503	0.0486	0.0481	0.0471	0.0475	0.0504
NSP's forecast opex partial productivity growth rates													
	NSP1	*NSP2*	*NSP3*	*NSP4*	*NSP5*	*NSP6*	*NSP7*	*NSP8*	*NSP9*	*NSP10*	*NSP11*	*NSP12*	*NSP13*
Technology	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%	3.46%
Returns to Scale	1.27%	1.27%	1.22%	1.23%	1.29%	1.14%	1.03%	1.03%	1.10%	1.01%	0.98%	0.99%	0.89%
Business Conditions	2.30%	2.26%	2.06%	2.23%	2.05%	2.06%	2.14%	2.00%	1.93%	1.87%	1.86%	1.92%	1.98%
Opex PP Growth Rates	**2.43%**	**2.46%**	**2.61%**	**2.46%**	**2.70%**	**2.54%**	**2.34%**	**2.49%**	**2.63%**	**2.60%**	**2.58%**	**2.53%**	**2.37%**

4.3. Regulatory application of econometric modelling results

The AER currently applies a 'base-step-trend' analysis to opex assessment, under which the base-year efficient opex is escalated for three changes:

- output growth;
- input-price escalation, accounting for partial factor productivity change; and
- 'step changes' due to changes in regulatory requirements or the external operating environment.

The level of recurrent opex in a year is:

$$Opex_{t+1} = Opex_t \cdot (1 + \Delta Output + \Delta Input\ Price - \Delta Opex\ Productivity) \tag{5}$$

Starting with the efficient opex in the base year, the level of annual opex required can be escalated over time by the annual 'rate-of-change'. The annual rate of change is the sum of the output growth rate and input price change rate, net of opex productivity change.

The econometric modelling of opex cost function provides direct information on the base-year efficient opex and opex productivity change components. This approach has been used previously in submissions by NSPs to the AER to assist in regulatory determinations. One example is Economic Insights (2012) that econometrically estimated opex efficiency levels and productivity growth rates for Victorian gas distribution businesses.

In the Model spreadsheet, the 'Reg App Opex' worksheet contains an example that uses opex efficiency and opex partial productivity results from the econometric modelling of the opex cost function to assess forecast opex and thus revenue allowances. As illustrated, opex cost modelling results could be used for two purposes:

- Assessing base-year opex efficiency: The Model assumes that a relatively inefficient NSP, in relation to its use of opex for a given level of technology, capital and outputs, can quickly achieve cost savings from removing the inefficiency in opex (e.g., within a year). The base-year efficient opex is the product of actual opex and one minus the opex efficiency score (derived from the econometric modelling). This is consistent with the approach typically undertaken by the OFGEM in electricity distribution price control reviews.
- Estimating opex productivity growth: For expositional purposes, the Model assumes that the observed trend productivity change is a good indicator of future productivity change. The opex partial productivity growth rate forecasts (derived from the parameter estimates from the econometric model) are used to adjust the forecast output growth and input price change to set the annual rate of change for cost escalation.

The resulting opex forecasts for the coming regulatory period provide an alternative set of estimates to NSP proposals and what the AER may determine under the 'revealed cost' approach. A comparison of the three sets of opex forecasts is presented in the 'Reg App Opex' worksheet.

- Under the benchmarking approach, observed inefficiency in the actual base-year opex is identified. The opex allowance is adjusted to account for the immediate removal of opex inefficiency.[8] Future cost reduction from observed trend productivity change is also accounted for.

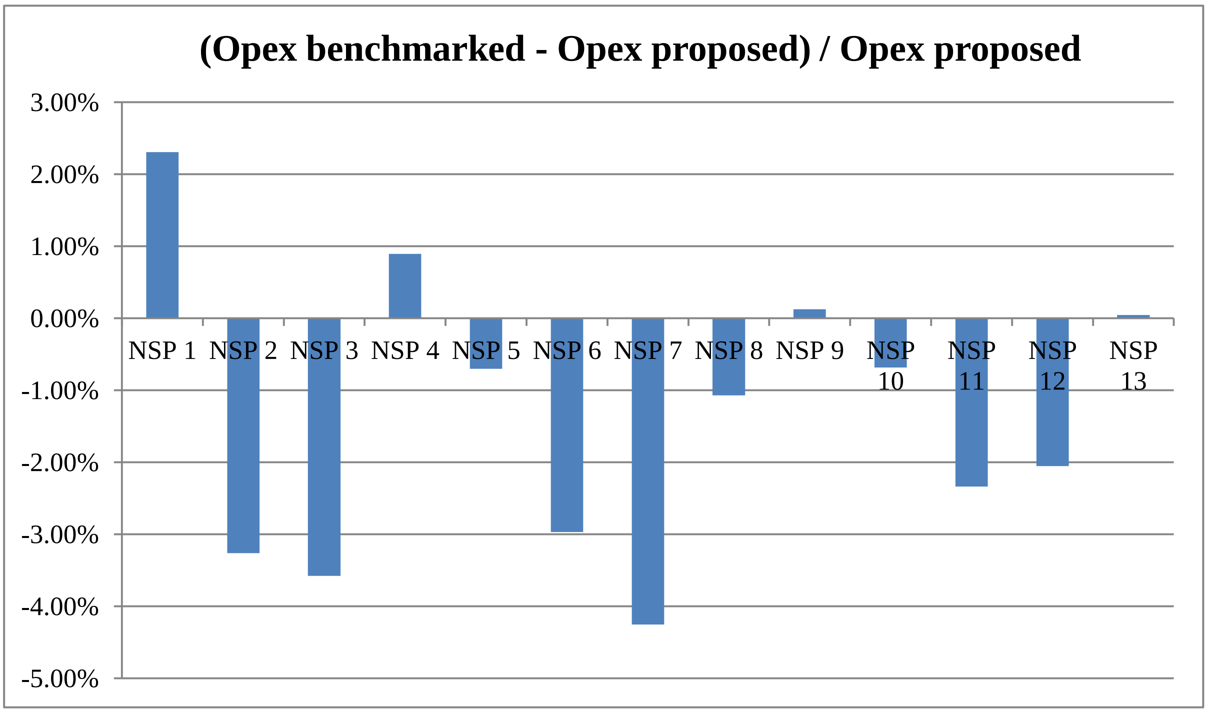
[8] In practice, only NSPs with a sufficiently high degree of identified inefficiency from a number of assessment methods may be subject to base-year opex adjustments.

- Under the 'revealed cost' approach, actual base-year opex is accepted as 'efficient' base-year opex, and NSPs are only required to pursue trend productivity change over time.
- For illustrative purposes, in forming the opex proposal from the NSPs series, it is assumed that each NSP considers its actual base-year opex to be efficient, but may have used different values of the opex rate-of-change components based on judgements and available information.

As modelled, the opex allowance determined under the benchmarking approach can be substantially different from estimates from the two alternative approaches.

Figure 7 summarises the opex benchmarking outcomes for individual NSPs. Total opex proposed by some NSPs (i.e., NSP 1, 4, and 9) are lower than reference opex suggested under economic benchmarking. They tend to be the more efficient NSP identified. For other NSPs, proposed opex exceeds the reference opex forecast identified under economic benchmarking by between 0.68 per cent and 4.26 per cent of total opex proposed. The failure to account for their potential to remove opex inefficiencies or pursue further productivity growth in some of these NSPs' opex proposals may explain some of the discrepancies in opex forecasts under the alternative approaches.

Figure 7: Opex Benchmarking Outcomes for the 13 NSPs



Note that the illustrative application of using the econometric opex cost function to assess expenditure forecasts focuses on opex only. Capital inputs are assumed to be fixed each period.

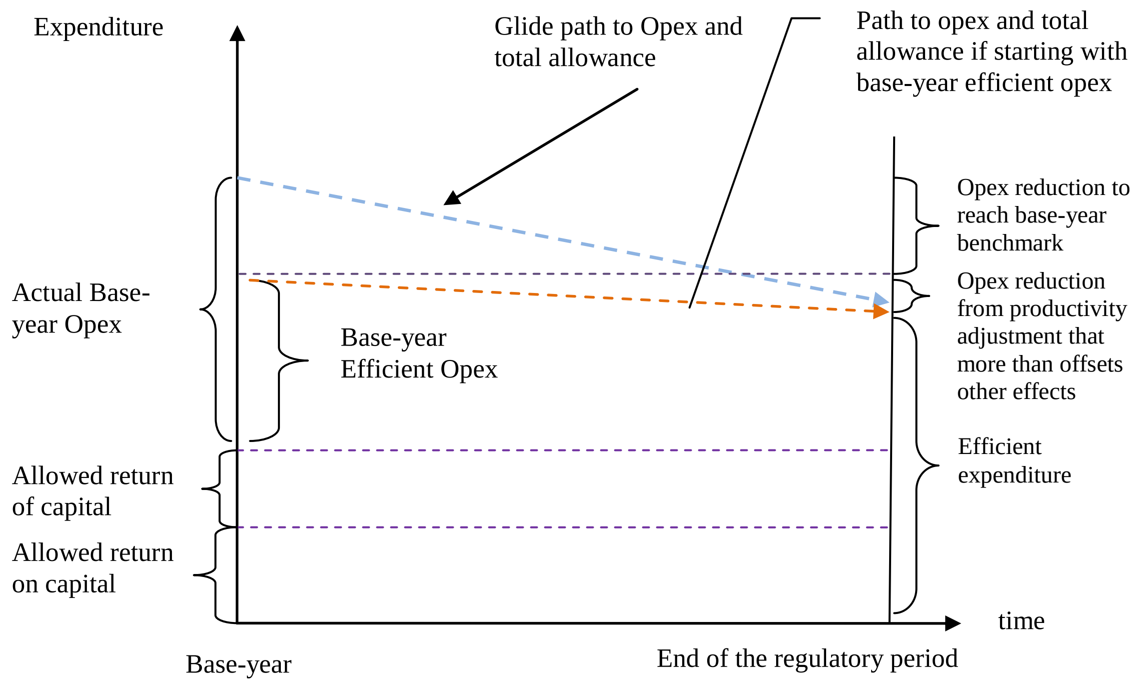
4.4. Furthering thinking on the Building Block Model application

Under the current building block model approach, an NSP is provided with an allowance to recover efficient opex, depreciation costs, and to earn a weighted average cost of capital (WACC) on its regulatory asset base. The AER must be satisfied that expenditure forecasts proposed by the NSPs reasonably reflect the criteria. Criteria include the efficient costs of meeting opex and capex objectives. Recent rules changes provide an increased role for benchmarking in assessing proposed expenditure forecasts.

The econometric opex cost function application illustrates the use of economic benchmarking methods to assess the reasonableness of opex. Economic benchmarking can also be applied to the assessment of total cost, as illustrated in section 3. However, the role of economic benchmarking in assessing capital expenditure may be limited due to significant differences across NSPs in terms of asset ages, investment pattern, and network structure and requirements.

Where economic benchmarking is used primarily for the assessment of forecast opex, the example application shown in the Model provides one way of forming a reference opex allowance (and thus total revenue allowance), under which the base-year efficient opex is estimated by benchmarking and further opex reduction from productivity gains are built in based on relationships identified across the sample and forecast changes in the NSP's relevant variables. This example application assumes that inefficiency in opex can be removed quickly, say within a year. The corresponding opex and total allowance path is shown by the orange dotted line in Figure 8 below.

Figure 8: Glide Path of Allowed Expenditure under the Building Block Model



However, the ability of an NSP to achieve cost savings by removing inefficiency in opex quickly may be limited by a number of factors. These factors include the scope of the cost inefficiency, business practices and the challenges of renegotiating workplace arrangements. It may be the case that efficient opex could only be achieved by the end of a five-year regulatory period (i.e., catching up with its peers). That is, it may take the full five-year regulatory period before the relatively inefficient NSP can 'catch up' with its peers. Additional cost savings may also be attained from productivity change over time due to technical progress (i.e., frontier shift of the industry).

The dotted blue line in Figure 8 shows a 'glide path' to align the expenditure determined on the basis of the 'revealed cost' approach, gradually during the entire regulatory period, to the level consistent with the ‘efficient benchmark’. The glide path takes into account both the ‘catch-up’ and ‘frontier-shift’ effects during the next regulatory period.

5. ***Principles for Using Economic Benchmarking Results***

5.1. Proposed application of economic benchmarking

The AER has proposed to use economic benchmarking as one component in a suite of tools used to assess expenditure forecasts. In this context, the successful application of economic benchmarking requires further consideration of application issues. This includes careful consideration of the setting and interpretation of the benchmark.

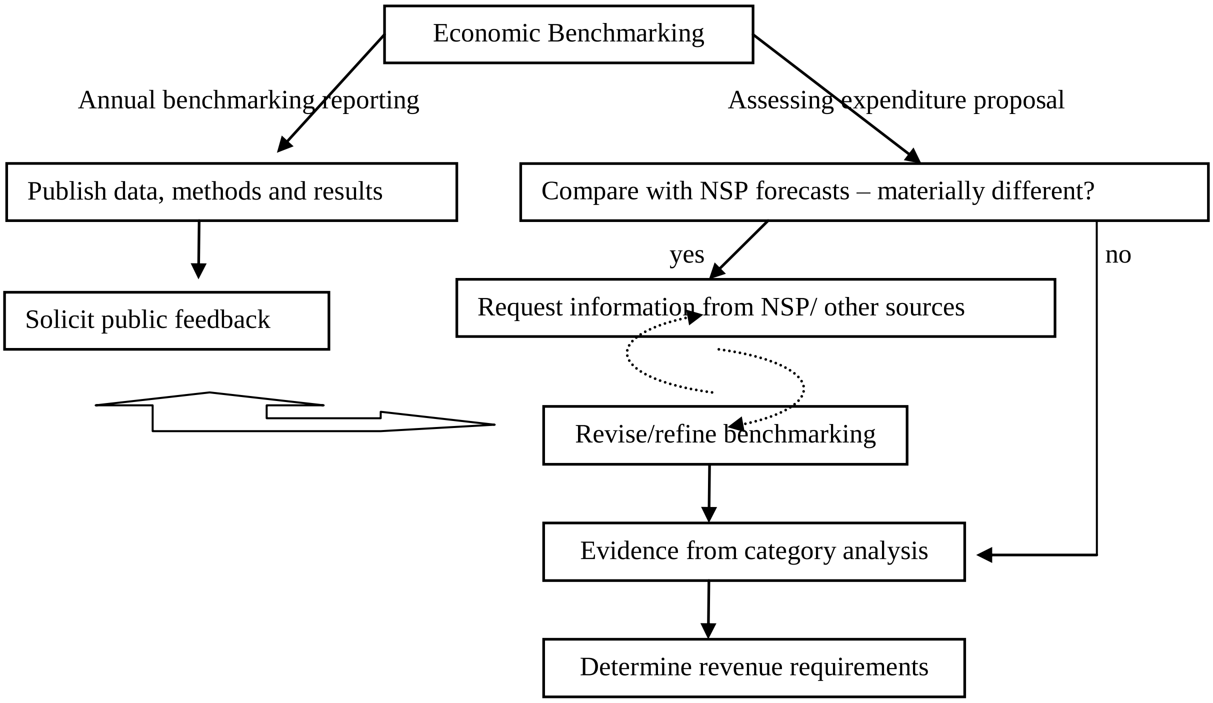
As suggested by the Productivity Commission (2012, p. 141), the objective of a regulatory regime should be to incentivise benchmarked businesses to operate close to, but not necessarily on, the frontier. This approach provides for an incentive gap to reward businesses for being dynamically efficient. This approach also addresses potential regulatory error. The implication is that caution should be exercised in relation to the use of raw results from frontier-based methods. For example, the DEA method does not account for potential errors in data and model specification when setting a benchmark.

In addition, it is necessary to develop an effective, iterative process to improve the application of economic benchmarking. The process, as proposed by the AER (2012, pp. 32-34) and illustrated in Figure 9 below, relies on regular communication with stakeholders throughout the process of preparing annual benchmarking reports and regulatory determinations. Stakeholders would then be provided with an opportunity to make submissions on the applications of methods in the Guidelines, as well as other data analyses in relation to the annual benchmarking and expenditure proposals.

With regard to the role of economic benchmarking in the assessment of an expenditure proposal, the AER’s proposal is to provide stakeholders with its views on the NSP’s expenditure forecast at the early ‘issues paper stage’ of a regulatory determination process, following the lodgment of the NSP’s regulatory proposal. Economic benchmarking and other assessment techniques will be used to make a preliminary assessment of the proposal. This is a ‘first pass’ at the expenditure assessment (AER, 2012, pp. 32-34). It is designed to identify areas of the expenditure forecasts that warrant further investigation.

Where efficient costs informed by economic benchmarking and other assessments are found to be materially different from the expenditure forecasts proposed, a detailed follow-up review may be required. This may involve more detailed review of proposed cost categories, including detailed engineering assessments. Additional information may be provided or requested from the NSP to justify its expenditure proposal. In some cases, this may lead to a refinement or revision of the benchmarking analysis and results. In other cases, the available evidence may support a departure from the ‘revealed cost’ approach to determining expenditure.

Figure 9: Process to Improve Economic Benchmarking and its Application



5.2. Holistic approach to the use of economic benchmarking

A number of factors should be considered when selecting a benchmarking method to calculate possible adjustments to forecast capex and opex. They include:

- Sample size – that is, the number of businesses that are available to include in the sample.
- Data availability and quality – for example, the presence of data noise will affect the methods that should be chosen.
- The intended use of the benchmarking results under the regulatory regime – Different types of analysis may be performed to measure comparative efficiency performance of NSP or industry-average productivity growth, to assess the efficiency of opex only or that of total cost.

Different benchmarking methods may produce somewhat different results because of underlying differences in their methodology. For example, using the same set of cost data, DEA and SFA methods estimate the cost frontier formed by the best-practice businesses, which can be somewhat different from the estimated cost function formed by conventional regression methods.

Consistency analysis should be performed to examine the robustness of benchmarking results in relation to alternative benchmarking methods and model specifications. Where the results differ materially, a justification for the use of the method and specification selected should be provided.

Bauer, Berger, Ferrier and Humphrey (1998) and Rossi and Ruzzier (2000) propose a set of ‘consistency conditions’ that should be examined when conducting sensitivity analysis on results produced by economic benchmarking methods. These include:

- the different methods should provide similar rankings of businesses;
- the different methods should identify mostly the same group of observations as ‘best practice’ and as ‘worst practice’;

- the results should consistently identify the same businesses as being relatively efficient or inefficient in different years, rather than varying markedly from one year to the next; and
- the efficiency scores generated by the different methods should be reasonably consistent with competitive conditions in the market.

For the purpose of using economic benchmarking as a tool under the 'first pass' test, it will be important to assess the consistency of alternative model specifications and methods in ranking and identifying the most and least efficient NSPs. Similarly, it will be desirable to consider the results of economic benchmarking results in conjunction with those of other high-level methods such as category analysis and to reject NSP forecasts only if there is agreement among the key methods and the NSP is identified as being inefficient by a sufficiently wide margin.

5.3 Other key points

While economic benchmarking provides useful information regarding relative efficiency performance of individual NSPs, the AER also recognises that economic benchmarking has its own limitations (see for example, ACCC/AER 2012a and 2012b; PC 2012). Therefore, the AER (2012, pp. 32-34) proposes not to use economic benchmarking as the sole tool for expenditure analysis, but to include it in a suite of tools used to assess expenditure forecasts. The successful application of economic benchmarking requires further consideration of a number of application issues, including (but may not be limited to):

- the continuous improvement of data collected;
- the setting of appropriate benchmarks; and
- the development of an effective but iterative process to improve economic benchmarking and its application.

6. Conclusions

This report, combined with the Model, provides example applications of economic benchmarking for regulatory purposes. In summary, less data-intensive benchmarking methods have been applied to a dataset of thirteen NSPs over six years for the purposes of illustrating the three principal regulatory uses of benchmarking likely to be used in the building blocks context identified in Economic Insights (2013a). In the Model, MTFP and DEA methods have been adopted for the assessment of total costs. It demonstrates how the 'total cost' assessment may be used in the regulatory context as a 'first pass' test. The results can also provide useful information regarding the likely productivity and efficiency improvements that the NSP may achieve in the longer term. The opex cost function modelling provides an example of its potential uses in assessing base-year efficient opex and quantifying the opex partial productivity growth rate under the opex rate-of-change roll-forward formula.

The report also sets out high-level principles on how economic benchmarking results could be used in assessing forecast expenditure in regulatory determinations.

Under the AER's proposed holistic approach to the use of economic benchmarking, it is important to check and ensure consistency of benchmarking results from alternative methods and model specifications. While there are a number of economic benchmarking methods, sample size, data availability and quality, and the intended use of the results will determine the methods that can be used.

References:

ACCC/AER (2012a), *Benchmarking Opex and Capex in Energy Networks*, ACCC/AER Working Paper No. 6, May.

ACCC/AER (2012b), *Regulatory Practices in Other Countries: Benchmarking Opex and Capex in Energy Network,* May.

Australian Energy Regulator (AER) (2012), *Better Regulation Expenditure Forecast Assessment Guidelines for Electricity Distribution and Transmission*, Issues Paper, Melbourne, December.

Banker, RD, A Charnes and WW Cooper (1984), 'Some Models of Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis', *Management Science*, 30, pp. 1078-1092.

Bauer, P, A Berger, G Ferrier and D Humphrey (1998), 'Consistency Conditions for Regulatory Analysis of Financial Institutions: A Comparison of Frontier Efficiency Methods', *Journal of Economics and Business*, 50 (2), pp. 85-114.

Caves D, L Christensen and W Diewert (1982b), 'Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers', *Economic Journal*, 92, pp. 73-86.

Charnes, A, WW Cooper and E Rhodes (1978), 'Measuring the Efficiency of Decision Making Units', *European Journal of Operational Research*, 2, pp. 249-444.

Coelli T, DSP Rao, C O'Donnell and G Battese (2005), *An Introduction to Efficiency and Productivity Analysis*, 2nd Edition, Springer.

Economic Insights (2009a), *International Benchmarking of Postal Service Productivity*, Report prepared for Australian Post, 5 June.

Economic Insights (2009b), *Electricity Distribution Industry Productivity Analysis: 1996–2008*, Report prepared for Commerce Commission, 1 September.

Economic Insights (2010), *A Model of Building Blocks and Total Factor Productivity-based Regulatory Approaches and Outcomes*, Report prepared for Australian Energy Market Commission, 29 June.

Economic Insights (2012), *Econometric Estimates of the Victorian Gas Distribution Businesses' Efficiency and Future Productivity Growth*, Report prepared for SP AusNet, 28 March 2012.

Economic Insights (2013a), *Outputs and Operating Environment Factors to be Used in the Economic Benchmarking of Electricity Distribution Network Service Providers*. Briefing Notes prepared for Australian Energy Regulator, 20 February.

Economic Insights (2013b), *Measuring DNSP Outputs and Operating Environment Factors for Economic Benchmarking of Electricity Distribution Network Service Providers*, Briefing Notes prepared for Australian Energy Regulator, 16 April.

Farrell, MJ (1957), 'The Measurement of Production Efficiency', *Journal of the Royal Statistical Society*, Series A, 120, pp. 253-278.

Jamasb T, P Nillesen and M Pollitt (2004), 'Strategic Behaviour under Regulatory Benchmarking', *Energy Economics*, 26, pp. 825-843.

Korhonen, P and M Luptacik (2004), 'Eco-Efficiency Analysis of Power Plants: An Extension of Data Envelopment Analysis', *European Journal of Operational Research*, 154, pp. 437-446.

Lawrence, D, P Swan and J Zeitsch (1991), ‘The Comparative Efficiency of State Electricity Authorities’, in P Kriesler, A Owen and MR Johnson (eds.), *Contemporary Issues in Australian Economics*, MacMillan.

Lovell, C (1993), ‘Production Frontiers and Productive Efficiency’, in H Fried, C Lovell and S Schmidt (eds), *The Measurement of Productive Efficiency*, Oxford University Press, New York, pp. 3-67.

Productivity Commission (2012), *Electricity Network Regulatory Framework*, Productivity Commission Draft Report, Volume 1, October.

Rossi, M and C Ruzzier (2000), ‘On the Regulatory Application of Efficiency Measures’, *Utilities Policy*, 9 (2), pp. 81-92.

Seiford, L and R Thrall (1990), ‘Recent Developments in DEA: The Mathematical Approach to Frontier Analysis’, *Journal of Econometrics*, 46, pp. 7-38.

Seiford, L and J Zhu (2002), ‘Modeling Undesirable Factors in Efficiency Evaluation’, *European Journal of Operational Research*, 142, pp. 16-20.

WIK-Consult (2011), *Cost Benchmarking in Energy Regulation in European Countries – Final Report*, Study for the Australian Energy Regulator, 14 December.

Yang, H and M Pollitt (2009), ‘Incorporating both Undesirable Outputs and Uncontrollable Variables into DEA: The Performance of Chinese Coal-Fired Power Plants’, *European Journal of Operational Research*, pp. 1095-1105.

Zeitsch, J and D Lawrence (1996), ‘Decomposing Economic Inefficiency in Base Load Power Plants’, *Journal of Productivity Analysis*, 7 (4), pp. 359-378.

Zhu, J (2009), *Quantitative Models for Performance Evaluation and Benchmarking*, Springer, New York.

Appendix 1: Data Construction

The dataset is constructed in a manner similar to Economic Insights (2010). It comprises of 13 hypothetical NSPs that are synthetic observations constructed from actual data on a small number of NSPs operating in similar operating environments. The actual NSP data are based on regulatory data submitted by the NSPs. Actual NSP data are not included in the synthetic sample.

The data for each hypothetical NSP cover the quantity, price and value of, two outputs and four inputs. STATA is used to construct the dataset and conduct the econometric analysis.

The following data-generation process is used:

1. Historic data levels and growth rates of a small number of actual NSPs are used to extrapolate six-year data for these NSPs.
2. Data for the 13 hypothetical NSPs that are derivations of the actual NSPs are constructed according to linear combinations.
3. The data are further adjusted by adding random variations. The variations are independent of variables. That is, for the same NSP, one output variable may increase while the other output variable decreases or changes at a different rate. The size of variable-specific random variation is within a specified percentage of the original value. A further random variation of a smaller magnitude is added to permit deviations from the given growth rates for a NSP over time, while maintaining the trend observed in the actual data.
4. The data are scaled in order to further maintain anonymity.

Additional data are either sourced externally or formed on theoretical or empirical grounds. These include the Wage Price Index (WPI) for the Electricity, Gas, Water and Wastewater (EGWW) sector produced by the Australian Bureau of Statistics (ABS).

Appendix 2: Description of the Spreadsheet Model

A spreadsheet has been constructed for the Model. A description of the data used in the spreadsheet is given in Appendix 1. The spreadsheet contains:

- The 'Readme' worksheet which summarises the spreadsheet and provides links to other sheets;
- One General worksheet ('Gen Data'), which covers values assumed for revenue shares, cost shares and other general data that are relevant for economic benchmarking analysis;
- One Generated-data worksheet ('NSP Data') which contains constructed data on the thirteen hypothetical businesses over six years;
- Seven Analytical worksheets which contain economic benchmarking and analysis of the generated data, including:
  - the derivation of raw MTFP using the index-number method and further analysis of the results;
  - the application of the DEA method to estimate cost efficiency and its decomposition into sources;
  - the econometric modelling of an opex cost function to assess opex efficiency and opex partial productivity growth; and
- Two Application worksheets that provide an illustration of two separate regulatory applications of economic benchmarking results:
  - regulatory application of opex cost modelling results to the assessment of opex under the BBM; and
  - regulatory application of total cost modelling results to the first-pass assessment of NSP expenditure forecasts under the BBM.

Raw-data worksheets

The 'Gen Data' worksheet contains general information that is relevant for economic benchmarking analysis. One piece of information is the industry-specific wage price index, which is used as a proxy for the opex price deflator. Other information includes the assumed values of output revenue shares and capital input cost shares that are formed on theoretical or empirical considerations. Note that the Model assumes:

- equal weights between the two outputs;
- cost shares between inputs X_2 and X_3 and input X_4 are 69 per cent versus 31 per cent; and
- capital user costs are 12.5 per cent of the value of RAB. This is consistent with earlier studies for New Zealand electricity distribution businesses; for example, Economic Insights (2009b, p. 15).

Generated-data worksheet

The 'NSP Data' worksheet contains generated data on thirteen hypothetical NSPs. This set of data is constructed from data of the historic levels and growth rates of a small number of actual NSPs. That is, observed historical levels and growth rates for each variable are used as a basis for creating the dataset.

The final dataset for the thirteen hypothetical businesses over six years is presented in the 'NSP Data' worksheet. This single worksheet contains pooled cross-sectional and time-series data covering relevant information for economic benchmarking. Key variables include:

- NSP number
- Year
- Quantity of each output (labeled as Y_1 and Y_2)
- Quantity of each input (labeled as X_1, X_2, X_3, and X_4)
- Relevant cost information (labeled by letter C), and
- Other explanatory variables (labeled by letter V).

A statistical summary of each key variable for the hypothetical NSPs is presented in Table A2.1 below. The summary statistics include the maximum value, minimum value, mean, and standard deviation.

Table A2.1: Summary Statistics of Key Output and Input Variables

Variable	Mean	Standard Deviation	Maximum Value	Minimum Value
Y_1	257870	13573	284748	227047
Y_2	769	48	888	689
X_1	51511	1234	54760	48451
X_2	22086	3598	28088	16369
X_3	3329	367	4136	2646
X_4	3257	116	3552	3064

Appendix 3: Summary Tables of Benchmarking Results

Table A3.1: Summary of Raw MTFP Results

NSP/Year	1	2	3	4	5	6	Average
1	1.0000	1.0122	1.0228	1.0316	1.0246	1.0353	1.0211
2	0.9743	0.9809	0.9938	1.0052	1.0181	1.0125	0.9975
3	0.9540	0.9751	0.9933	0.9977	0.9995	1.0003	0.9866
4	0.9842	0.9891	1.0030	1.0210	1.0207	1.0336	1.0086
5	0.9519	0.9724	0.9829	0.9814	1.0019	1.0036	0.9823
6	0.9765	0.9848	0.9913	1.0042	1.0049	1.0163	0.9963
7	0.9756	0.9871	1.0027	1.0052	1.0174	1.0161	1.0007
8	0.9472	0.9476	0.9555	0.9680	0.9726	0.9834	0.9624
9	0.9593	0.9784	0.9743	0.9873	1.0036	1.0087	0.9853
10	0.9515	0.9646	0.9811	0.9867	0.9940	1.0036	0.9802
11	0.9478	0.9631	0.9824	0.9857	0.9987	1.0051	0.9805
12	0.9513	0.9656	0.9701	0.9753	0.9985	0.9989	0.9766
13	0.9523	0.9652	0.9906	0.9886	1.0029	0.9994	0.9832
Average	**0.9635**	**0.9759**	**0.9880**	**0.9952**	**1.0044**	**1.0090**	**0.9893**

Table A3.2: Raw DEA Technical Efficiency (Input-oriented CRS DEA)

NSP/Year	1	2	3	4	5	6	Average
1	1.000	1.000	1.000	1.000	0.994	1.000	0.999
2	1.000	0.999	0.993	0.996	0.998	1.000	0.998
3	0.991	0.987	1.000	1.000	1.000	1.000	0.996
4	1.000	0.994	0.996	1.000	0.997	1.000	0.998
5	0.965	0.974	0.973	0.966	0.984	0.985	0.975
6	1.000	0.999	0.992	0.995	0.993	1.000	0.997
7	1.000	0.996	1.000	0.996	1.000	1.000	0.999
8	0.976	0.961	0.961	0.970	0.966	0.974	0.968
9	0.982	0.985	0.974	0.979	0.988	0.994	0.984
10	1.000	0.992	1.000	1.000	0.992	1.000	0.997
11	0.998	0.986	0.997	0.990	0.991	1.000	0.994
12	0.983	0.980	0.979	0.978	0.997	1.000	0.986
13	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average	**0.992**	**0.989**	**0.990**	**0.990**	**0.992**	**0.996**	**0.991**

Table A3.3: Raw DEA Allocative Efficiency (Input-oriented CRS DEA)

NSP/Year	1	2	3	4	5	6	Average
1	0.975	0.979	0.989	0.997	0.996	1.000	0.989
2	0.947	0.960	0.968	0.976	0.987	0.978	0.969
3	0.929	0.954	0.960	0.963	0.973	0.973	0.959
4	0.956	0.970	0.973	0.988	0.990	1.000	0.980
5	0.954	0.965	0.977	0.982	0.986	0.986	0.975
6	0.958	0.968	0.976	0.983	0.991	1.000	0.979
7	0.948	0.962	0.975	0.981	0.987	0.987	0.973
8	0.938	0.953	0.961	0.966	0.974	0.978	0.962
9	0.947	0.965	0.971	0.982	0.987	0.988	0.973
10	0.937	0.955	0.962	0.971	0.983	0.992	0.967
11	0.917	0.944	0.955	0.965	0.983	0.980	0.957
12	0.939	0.958	0.970	0.978	0.982	0.984	0.969
13	0.923	0.943	0.968	0.970	0.983	0.988	0.963
Average	**0.944**	**0.960**	**0.970**	**0.977**	**0.985**	**0.987**	**0.970**

Table A3.4: Raw DEA Cost Efficiency (Input-oriented CRS DEA)

NSP/Year	1	2	3	4	5	6	Average
1	0.975	0.979	0.989	0.997	0.990	1.000	0.988
2	0.947	0.959	0.961	0.972	0.984	0.978	0.967
3	0.921	0.942	0.960	0.963	0.973	0.973	0.955
4	0.956	0.964	0.969	0.988	0.987	1.000	0.977
5	0.921	0.940	0.951	0.949	0.970	0.971	0.950
6	0.958	0.966	0.969	0.978	0.984	1.000	0.976
7	0.948	0.958	0.975	0.977	0.987	0.987	0.972
8	0.915	0.916	0.924	0.937	0.942	0.953	0.931
9	0.929	0.950	0.946	0.962	0.976	0.983	0.958
10	0.937	0.947	0.962	0.971	0.975	0.992	0.964
11	0.915	0.932	0.952	0.955	0.975	0.980	0.952
12	0.923	0.939	0.949	0.956	0.979	0.984	0.955
13	0.923	0.943	0.968	0.970	0.983	0.988	0.963
Average	**0.936**	**0.949**	**0.960**	**0.967**	**0.977**	**0.984**	**0.962**

Table A3.5: Opex Cost Function Regression Results

Coefficient	Estimate	Standard Error
LN(Y_1)	0.196*	0.104
LN(Y_1)^2	-1.600	1.684
LN(Y_2)	0.302	0.181
LN(Y_2)^2	1.354	2.158
LN(X_k)	0.183	0.126
TT	-0.035***	0.010
LN(Z_1)	0.357***	0.117
_cons	0.130***	0.040
N	78	
R^2	0.594	
adj. R^2	0.553	

Notes: significant level: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3.6: Opex Efficiency Results

NSP/Year	1	2	3	4	5	6	Average
1	1.036	1.032	1.043	1.037	1.025	**1.024**	1.033
2	0.983	0.981	0.988	0.992	0.985	**0.983**	0.986
3	0.973	0.989	0.988	0.983	0.981	**0.971**	0.981
4	1.009	1.006	1.005	1.005	1.001	**1.011**	1.006
5	0.999	1.001	1.006	0.997	1.006	**0.997**	1.001
6	1.002	1.005	1.001	1.011	0.988	**0.980**	0.998
7	0.979	0.993	0.990	1.000	1.000	**0.987**	0.991
8	1.005	1.002	0.990	0.996	0.999	**0.998**	0.998
9	1.002	1.011	0.993	0.996	1.001	**0.999**	1.001
10	0.984	0.992	0.988	0.984	0.993	**0.989**	0.988
11	0.995	1.015	1.015	1.017	1.015	**1.017**	1.013
12	1.010	1.022	1.020	1.013	1.024	**1.017**	1.018
13	0.983	0.974	1.001	0.988	0.995	**0.993**	0.989
Average	**0.997**	**1.002**	**1.002**	**1.001**	**1.001**	**0.997**	**1.000**