COMPARATOR AND COHORT BENCHMARKING OF LDC COST

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Executive Summary

Last December the Ontario Energy Board (OEB) released a report with findings and recommendations of a consultant, Robert Camfield, in its comparators and cohorts (C&C) inquiry. This inquiry concerns the use of statistical benchmarking to regulate Ontario's local power distribution companies (LDCs). Board staff have expressed an interest in benchmarking generally and the C&C method particularly.

C&C benchmarking is a form of index-based benchmarking that involves the grouping of LDCs into cohorts with similar business conditions. The costs incurred by LDCs in each cohort are compared. The comparisons can help to identify cost anomalies.

Mr. Camfield was retained by the Board to perform some preliminary empirical work on the C&C concept. His work included some econometric cost modeling based on a sample of operating data for a number of Ontario LDCs. Model results were used in a statistical clustering analysis to identify suitable cohort groups. Camfield, additionally, suggested comparators that can be used to perform cost diagnostics in cohorts.

Pacific Economics Group ("PEG") has advised numerous energy utilities on the use of benchmarking in regulation. We have performed dozens of sophisticated cost benchmarking studies in industries ranging from power, water, and gas distribution to power transmission and bundled power service. Hydro One Networks has retained us to draw on this experience in appraising and commenting on the Camfield report.

Basic Concepts

Our report begins with a review of some basic concepts needed for rigorous appraisal of the basic C&C approach and Camfield's proof of concept work. The review encompasses cost drivers, econometric cost research, capital cost measurement, and index-based benchmarking. The cost driver discussion emphasizes the multi-dimensional character of utility output. It also highlights the special challenges encountered when partial cost categories such as operating expenses are examined. The efficient use of operating inputs, for example, depends on a utility's use of capital.

The econometric discussion generally supports Camfield's proposal to use statistical clustering analysis based on econometric cost research to identify suitable cohorts for cost comparisons. It also provides useful principles for cost model development. Economic theory and tests of statistical significance should guide model development. Models should do the best possible job of explaining sample variation.

The capital cost measurement section underlines the complexity and difficulty of accurate capital cost benchmarking. The discussion of index-based regulation emphasizes the wide variety of cost conditions that can influence cost level comparisons of the kind proposed. It also highlights some desirable indexing tools that can be useful in the development of comparators. These include multi-factor productivity indexes and output measures that can summarize comparisons of multiple output dimensions.

Role of Benchmarking in Regulation

A major attraction of benchmarking for regulators is the opportunity to economize on regulatory cost. While the potential cost savings from benchmarking are palpable, it is important to remember that regulators, like utilities, are subject to quality standards. In most jurisdictions, rates are expected by law to satisfy a just and reasonable standard. Rates above or below this standard are unfair to customers or shareholders, respectively. Rates that fluctuate around this standard can raise the cost of utility operation by raising utility operating risk. Benchmarking may not be desirable on balance if the quality of the resultant decisions is markedly below the quality of decisions that would be rendered using traditional regulation.

Various benchmarking methods are useful in regulation. In choosing among these, we must balance considerations of accuracy and regulatory cost. An inaccurate method can lead to unfair appraisals and raise the cost of utility operation by raising operating risk. Methods should play a more limited role in the regulatory process to the extent that they are inaccurate.

The Power Distribution Business

A responsible benchmarking exercise should recognize certain essential features of the power distribution business. These include the following.

- Output is generally multidimensional.

- System extensiveness (*e.g.* the distance over which power is transported) can be important driver of the costs of local power delivery and customer care services.
- A variety of business conditions other than input prices and workload can affect cost. For the local power delivery business, these include reliability, terrain, the extent of forestation, system age, the extent of system undergrounding, and the extent of voltage transformation. For customer care services, these include the mix of customers, the services provided, service quality, and the extent of demand-side management activity.
- Local power delivery opex and capex have noteworthy periodicity. Line maintenance expenses, for example, can fluctuate from year to year. Capex follows load growth so that differences in historical load growth patterns lead to differences in system age.
- Relationships between cost and external business conditions can be highly non-linear.

Appraisal of the Camfield Report

Cost Performance Variables

Camfield proposes separate C&C treatment of diverse sub-categories of LDC costs. This raises several issues that the Board should carefully consider.

- Separate treatment of capex and opex can lead to incorrect performance appraisals unless the substitutability of these inputs is duly recognized. Decisions on the capitalization of OM&A expenses should be closely monitored.
- Consideration of detailed cost categories that involve arbitrary allocations of costs can also lead to incorrect performance appraisals. One concern here is the proposed breakdown of customer care expenses into Billings and Collections and Customer Information. Another is the separate consideration of administrative expenses.
- Accurate capital cost benchmarking is challenging due in part to the unsuitability of the currently available data. More accurate methods for measuring capital cost are complex and costly to implement and still do not ensure proper controls for differences in historical output growth patterns. The benchmarking of older

capital investments can materially raise LDC operating risk. These problems help to explain why many regulators who use benchmarking do not apply it to capital costs.

Econometric Work

Camfield develops econometric models for several cost categories that have considerable explanatory power. Special features of the sample, however, make the achievement of high explanatory power likely whether or not the models do a good job of identifying the true cost drivers. The Board should commit to developing the best cost models that can be supported by the available data. Camfield proposes to use only 2004 data for his final regression work whereas his proof of concept research is based on two years of data. A smaller sample would reduce the ability to identify important cost drivers.

Statistical Clustering Analysis

Camfield has not yet provided a detailed explanation of his statistical clustering analysis. Such analyses yield a wealth of information that should be considered in a responsible use of the C&C method. The relevant results include the similarity in the business conditions of each chosen cohort and measures of how the business conditions of individual LDCs differ from the norms for the cohort.

Selection of Comparators

Camfield does not provide general principles for the selection of comparators that are used in cost diagnostics. The comparators that he does suggest are generally simple and highly partial measures of performance. They involve a lot of overlapping and do not individually provide evidence of cost inefficiency. It is not clear how the results of such comparators would be weighted. Our discussion of indexing methods points the way to more useful comparators. The comparators should also include measures of the similarity of the business conditions of each LDC to the norms for the cohort.

Identification of Anomalies

The report devotes little attention to how the C&C results would ultimately be used to identify cost anomalies. The imprecision of the methodology and imperfections of the data should be duly recognized. Statistical tests of efficiency hypotheses are desirable due in part to their ability to integrate consideration of a method's precision.

Use of the Results

The experimental character of the C&C methodology should be carefully considered in deciding how determinations of anomalies are used. It seems appropriate to use the results only to screen rate applications and identify those that merit more detailed review.

Role of Benchmarking in Regulation

Camfield's more general discussion of the role of benchmarking in regulation focuses chiefly on the issue of regulatory cost. His discussion does not give balanced consideration to the quality of decisions that would result from the C&C process. It would be desirable for the Board to recognize the quality issue and the potential impact of inaccurate benchmarking methods on operating risk in its final C&C decision.

Camfield's Conclusions

Camfield asserts that he has proved the feasibility of the C&C concept and recommends its implementation. We find that the results reported do not by themselves provide sufficient support for proceeding on the course Camfield recommends. While he properly acknowledges the serious deficiencies in the available data, the collection of better data will not by itself make the C&C approach acceptable. The methodology should, in fact, be changed in several ways if additional work is to be performed. Important dimensions of this mid-course correction include:

- Exclusion of capital cost as a performance variable
- Consolidated treatment of customer care expenses
- Approaches to cost modeling that recognize substitution possibilities
- Reporting of key clustering analysis statistics

- Reconsideration of comparators
- Development of statistical tests of efficiency hypotheses

1. Introduction

On Tuesday 14 December the Ontario Energy Board (OEB) released a report containing findings and recommendations of a consultant, Robert Camfield, in its comparators and cohorts inquiry.[1] A follow-on presentation and conference call on his work took place in early January. The inquiry concerns the use of statistical benchmarking to regulate Ontario's local power distribution companies (LDCs). Distributors and other stakeholders in Ontario regulation have been asked to comment.

The OEB, with jurisdiction over more than 90 LDCs, has long expressed an interest in benchmarking. In 1998, Board staff issued a report on PBR Options that includes a discussion of Yardstick Competition (YC). It explains the general concept of YC as follows:

> Intrinsic cost differences are accommodated in the YC approach by a multi-phased implementation process that places each firm in a tournament with similarly situated firms. First, all firms would provide information on market and customer profiles, operations, revenues, rates, and costs. Second, statistical modeling of this information would identify and quantify intrinsic cost differences.. Results of step 2 ... can be used to create a subgroup classification for review. Third, the subgroup characteristics defined in step 2 can be applied to the information supplied by each firm in step 1 to create peer group assignments for all firms. Fourth, information provided in step 1 would be used to calculate average costs for each peer group. These average costs by peer group would be established as external benchmarks for each firm's average price.[2]

A collaborative Yardstick Grouping Task Force was formed in 1999 to explore this idea. The terms of reference of the Task Force included the following:

- Determine the number of yardstick groupings and the assignment of utilities to groups
- Assess the specific benchmarks and their implications.

[1] Robert Camfield, "Findings and Recommendations: Comparators and Cohorts for Electricity Distribution Rates", mimeo, December 2004.
[2] *ibid*, p. 15.

From the beginning of the 2006 rate update the Board has expressed an interest in implementing a "comparator and cohort" approach to benchmarking. In a June 2004 memorandum, for instance, the number one entry on its list of potential issues for the generic methodology review is "Use of 'comparators' to assist prudency review of LDCs costs."[3] It explains in this memo that:

> Board staff would compare various operational and financial statistics between LDCs as a means of identifying outliers and anomalies...The Board wants useful comparators to be identified...For example, costs per customer, billing and collection expenses per customer...[4]

It then asks

> To further aid in the use of comparators as part of the rate application review process, can the various Ontario LDCs be grouped into a smaller number of cohorts or peers (for example, based on size, operating characteristics, structure, or operational and management processes)?[5]

A 2006 EDR Executive and Working Group was established to address these issues.

Robert Camfield of Christensen Associates was retained by the Board last fall to undertake some preliminary C&C empirical work. He states on page 2 of his report that its purpose is to help the Board and its staff

1. determine whether Comparators and Cohorts mechanism [sic] is feasible and can serve as a practical tool to assist in the processing of the rate applications for rebased rates in 2006.
2. determine a basis for the comparison of costs of Ontario's electricity distributors. These cost factors are referred to as Comparators; and
3. determine the data and information reporting elements.[6]

Pacific Economics Group ("PEG") has advised numerous energy utilities on the use of benchmarking in regulation. We have performed dozens of sophisticated cost benchmarking studies in industries ranging from power, water, and gas distribution to power transmission and bundled power service. Our practice is international and has to

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[3] Ontario Energy Board, *Process for Establishing 2006 Electricity Distribution Rates*, June 16 2004.
[4] *ibid*, p. 1.
[5] *ibid*, p. 1.
[6] Camfield *op cit* p. 5.

date included studies in ten countries. Hydro One Networks has retained us to draw on this experience in appraising and commenting on the Camfield report.

The plan for this evidence is as follows. An introduction to cost benchmarking is provided Section 2. The use of benchmarking in regulation is considered in Section 3. There follows in Section 4 a discussion of characteristics of the power distribution business that are important in the preparation of a good benchmarking study. Section 5 draws heavily on these discussions in providing a detailed critique of the Camfield report.

2. Introduction to Cost Benchmarking

In this section, we consider some important concepts that are needed in a rigorous appraisal of the proposed C&C method. The discussion is non-technical. Readers interested in more technical treatments of the topics are referred to the Appendix.

2.1 What is Benchmarking?

The word benchmark comes originally from the field of surveying. The *Oxford English Dictionary* defines the term as

> A surveyors mark, cut in some durable material, as a rock, wall, gate pillar, face of a building, etc. to indicate the starting, closing, ending or any suitable intermediate, point in a line of levels for the determination of altitudes over the face of a country.

The term has subsequently been used more generally to indicate something that embodies a performance standard and can be used as a point of comparison in performance appraisals.

A *quantitative* benchmarking exercise commonly involves one or more gauges of activity. These may be called performance *variables*. The values of the performance variables achieved by the entity under scrutiny are compared to benchmark values that reflect performance standards. Given information on the cost of a utility and a certain cost benchmark we might, for instance, measure its cost performance by taking the logged ratio of the two values.

Benchmarks are often developed using a sample of data on the operations of agents that are involved in the activity being appraised. Statistical methods are useful in both the calculation of benchmarks and in the comparison process. An approach to benchmarking that prominently features statistical methods is called statistical benchmarking.

2.2 Cost Drivers

For costs and many other kinds of performance indicators, it is widely recognized that the values achieved by companies depend partly on differences in their operating efficiency and partly on differences in external conditions. In cost research, these conditions can be generally termed business conditions and are often called cost drivers. Customer service expenses will, for example, vary with the number of customers served.

Performance benchmarks must reflect external conditions. Since performance is measured by comparisons to benchmarks, the cost performance of each company depends on the cost that it achieves *given the business conditions that it faces*. When trying to benchmark accurately, it follows that the most important tasks include the identification of relevant business conditions and a consideration of their impact.

Economic theory is useful in identifying cost drivers. We begin by positing that the actual cost incurred by a company is the product of the *minimum achievable* cost and an efficiency factor.[8] The goal of benchmarking is to accurately estimate the efficiency factor.

Consider next that, under certain reasonable assumptions, cost functions exist that relate the minimum cost of an enterprise to quantifiable business conditions in its service territory. Two kinds of cost functions yielded by this theory are useful in benchmarking. One is the *total* cost function in which the minimum total cost of an enterprise is a function of sets of input prices, output quantities, and variables representing miscellaneous other relevant business conditions. The latter group of variables are sometimes conveniently called "Z" variables.

Note immediately that the theory allows for the existence of *multiple* output variables. This is important because it is often not possible to adequately measure the workload a utility using only one output variable. It is also noteworthy that theory allows for the possibility that numerous business conditions other than input prices and output quantities can affect the minimum cost of service.

Regulators considering the appropriate revenue requirement of a company often have special interest in certain categories of cost. A familiar example is operation, maintenance, and administration (OM&A) expenses (opex). The interest in these expenses is due in part to the fact that they are subject to greater control by utilities from year to year than are capital costs.

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[8] This factor has a value that is greater than or equal to one. Thus the higher the factor, the greater is inefficiency.

Restricted cost functions are useful for identifying the full range of relevant cost drivers in this case. In such a function, the minimum cost of a group of inputs depends on the prices of those inputs, and on output quantities, and other business conditions. It is also a function of the amounts of *other inputs* that the company uses. The minimum level of opex, for instance, depends on the *capital* inputs in use.[9]

The existence of the other input variables in restricted cost functions means that a fair appraisal of the efficiency with which a utility uses a certain class of inputs must consider the amounts of *other* inputs that it uses. Suppose, for example, that the focus of inquiry is opex. It is then germane that the minimum level of opex depends on the capital inputs that the company uses. A firm may have unusually high opex because it has a highly depreciated rate base.

As a practical matter, it is not always possible to measure capital quantities accurately. However, variables can sometimes be computed that represent important characteristics of the capital stock that may have an influence on opex. For example, one might employ the ratio of accumulated depreciation to net plant value as a measure of system age.

The list of other inputs that is relevant lengthens as we focus on more and more specific cost categories. Suppose, for example, that the *labour* expenses of a company are at issue. Theory suggests that the minimum level of labour expense depends on the amounts of *other* (non-labour) OM&A inputs a company uses. It is easier to economize on labor inputs, for example, if a company is outsourcing a lot of its tasks to other companies. By the same token, a company with high labour costs might do very little outsourcing.

2.3 Econometric Cost Research

The relationships between the costs of utilities and the business conditions that they face can be estimated using econometric methods. Econometric research is based on certain critical assumptions that should be understood in considering the proposed C&C methodology. The most important assumption, perhaps, is that the values of some

[9] Capital quantities are generally less variable in the short run than the quantities of OM&A inputs. For this reason, cost functions for opex are sometimes called "short run" cost functions.

economic variables (called dependent variables), are functions of certain other variables (called explanatory variables) and error terms. In an econometric cost model, cost is the dependent variable and the cost drivers are the explanatory variables.

The error term in an econometric cost model is the difference between actual cost and the cost that is explained by the included cost function variables. It reflects any errors in the specification of the model, including the exclusion from the model of relevant business conditions and problems in the measurement of the business conditions and in the estimation of their cost impact. Error terms are a formal acknowledgement of the fact that the cost model is unlikely to explain the full impact of external business conditions on minimum cost. It is customary to assume that error terms are random variables with probability distributions that are determined by additional coefficients, such as mean and variance.

Specific forms must be chosen for econometric cost models. In these forms, the sensitivity of cost to the value of each included explanatory variable is determined by coefficients. Forms that are widely used in econometric research include the linear, the double log, and the translog. These functions vary in the flexibility with which they capture relationships between costs and cost drivers.

A branch of statistics called econometrics has developed procedures for estimating coefficients of economic models using historical data on the dependent and explanatory variables.[10] For example, cost model coefficients can be estimated econometrically using historical data on the costs incurred by utilities and the business conditions they faced. A positive estimate for a coefficient corresponding to the number of customers, for instance, would reflect the fact that the costs reported by sampled companies tended to be higher the greater were the number of customers that they served.

The results of econometric research are useful in selecting business conditions for cost models. Specifically, tests can be constructed for the hypothesis that the coefficient for a business condition variable equals zero. A variable can be deemed a statistically significant cost driver if this hypothesis is rejected. Statistical significance is a sensible criterion for the inclusion of variables in cost models. The t statistic formula indicates factors that are relevant in determining the statistical significance of a candidate cost

[10] The act of estimating model coefficients is sometimes called regression.

driver. Statistical significance is more likely to be confirmed when the econometric work involves a large and varied sample.

The sample used in model estimation can in principle be a time series consisting of data over several years for a single firm, a cross section consisting of one observation each for each of several firms, or a panel data set that pools time series data for several companies. Since larger samples are an aid in the identification of cost drivers, it is generally desirable to use panel data sets rather than cross sections when these are available.

2.4 Cost Elasticities

The concept of cost elasticity is often used in cost research and merit brief explanation. The elasticity of cost with respect to a certain business condition variable is the percentage change in cost that results from a one percent change in the value of the variable. Cost elasticities can be derived from econometric estimates of cost model coefficients.

2.5 Capital Cost

Camfield considers in his report the option of benchmarking the capital costs of Ontario LDCs. This issue is valid since capital inputs play important roles in utility operations. They are especially important in network businesses like power and natural gas transmission and distribution. In these businesses, capital typically accounts for half or more of total cost depending upon how utility plant is valued. It is therefore understandable that regulators would wish to assess the efficiency with which capital is used.

Accurate benchmarking of capital cost requires an estimate of the cost and a means of decomposing it into a capital service price index and a capital quantity index. Capital service price indexes indicate the annual cost of owning a unit of capital. They differ from indexes that measure capital *asset* prices --- the cost of acquiring a unit of plant. Service price indexes are so-called because prices for the rental of a unit of capital in competitive rental markets (*e.g.* those for real estate or automobiles) tend to reflect the cost of owning capital.

The cost of capital ownership has several components. One is the opportunity cost of having funds tied up in ownership. To the extent that a company uses shareholder funds for this purpose, this is the profits that are foregone from alternative investments. To the extent that it borrows the money, this is the interest that it must pay. Another important component of capital cost is depreciation. This can be computed in a number of different ways. Consider, additionally, that the *net* cost of plant ownership in a given year is less than the *gross* by the appreciation in the value of plant --- capital gains.

The computation of depreciation and opportunity cost requires a valuation of utility plant. Two basic approaches to valuation are used. One is book (historical cost) valuation. The other is current (replacement cost) valuation.

Regulators must choose a method for calculating capital cost to establish revenue requirements. North American regulators use book valuations of plant and straight line depreciation.[11] Capital cost is not reduced by the amount of capital gains. These practices influence the way that utilities report their capital cost. For example, the available data on depreciation and gross and net plant value all reflect book valuations and straight line depreciation. The reported values of plant additions are, on the other hand, consistent with various approaches to capital cost measurement.

The way in which utilities report capital costs complicates capital cost benchmarking. Differences in the reported depreciation and net plant value of companies reflect differences in the historical timing of plant investments. For example, utility A can have the same amount of plant as utility B but have a lower net plant value if its plant is older on average. Differences in the reported depreciation and net plant value of companies also reflect differences in depreciation practices.

It is possible to decompose capital cost into a price and a quantity when there is straight line depreciation and book valuation of plant. However, the required formulas are complex. Implementation also requires extensive information on past plant additions.

The calculation of a capital quantity index can be challenging. The first step in its calculation is to estimate the net *current* value of plant in a benchmark year. This is achieved by adjusting the reported net plant *book* value for the asset price inflation that occurred between the years of each plant addition and the benchmark year. Construction

[11] Replacement valuations are used in some other countries, including Australia.

cost indexes are commonly used in such an exercise to measure asset price inflation. Issues encountered in the practical implementation of this procedure include how many years prior to the benchmarking year to consider and the weight that should be applied to each year.

The accuracy of this general approach to capital cost measurement is increased to the extent that the benchmark year is far in the past since this reduces the sensitivity of results to the benchmark year revaluation method. In the electric power research of PEG that uses U.S. data, for instance, we use *1964* as the benchmark year. Computing past values of capital quantity indexes is complicated by past mergers and acquisitions involving sampled firms.

The next step in the development of a capital quantity index is to calculate how its value changes over the year due to depreciation, plant investments, and retirements. Perpetual inventory equations are commonly used for this purpose. Such equations relate the value of the capital quantity index in a given year to the value of plant additions (and perhaps also retirements) and depreciation in that year, as well as the value of the capital quantity index in the prior year. The approach used to calculate depreciation is commonly standardized.

When capital cost is calculated using such methods, two utilities that own the same *quantity* of capital will have the same capital cost. However, the amount of capital that utilities use is still quite sensitive to their patterns of plant additions over the years. For example, two LDCs with similar systems can still have very different capital costs and quantities if one system has an average asset age of 25 years while the other has an average asset age of 35 years. It follows that while the use of perpetual inventory equations is a step in the direction of accurate capital cost benchmarking, it is not a complete solution to the benchmarking problems posed by differences in past patterns of investment.

2.6 Index-Based Approaches to Benchmarking

The C&C methodology is an example of an index-based approach to statistical benchmarking. This section discusses key concepts in index-based benchmarking. Some useful benchmarking formulas are presented in the Appendix.

Index Basics

An index is defined in one respected dictionary as "a ratio or other number derived from a series of observations and used as an indicator or measure (as of a condition, property, or phenomenon)".[12] In the present application, indexing involves the calculation of ratios of the values of performance variables for a subject utility to corresponding values that represents tendencies of the same variables among a sample of utilities. The group of companies included in a sample used for indexing is called, variously, a cohort or a peer group.[13] The statistic that is most widely used to characterize the sample is the sample mean value.

These concepts are usefully illustrated by the decision process by which sports writers decide to elect athletes to the National Baseball Hall of Fame. Statistical benchmarking plays a major albeit informal role in player selection. Pitchers, for example, are evaluated using multiple performance variables that include innings pitched, earned run average, and the number of strikeouts. The values of indicators for candidates are compared to the averages for players that have already been elected to the Hall. These averages reflect a Hall of Fame performance standard.

A useful property of indexes is their ability to summarize the results of multiple comparisons. Consumer price indexes are familiar examples. These summarize the inflation in the prices of hundreds of goods and services. Summaries of comparisons commonly involve the calculation of weighted averages.

To illustrate the advantages of complex indexing in benchmarking, recall first that theory allows for cost to depend on multiple output quantity variables and that multiple variables are needed to measure utility work load. We might, then, wish to construct an output quantity index that is a weighted average of comparisons for several output measures. In a benchmarking application, it make sense for the weights of an output quantity index to reflect the relative importance of the output measures as cost drivers. Econometric research is useful in this regard. We can, for example, use as the weight for

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[12] *Webster's Third New International Dictionary of the English Language Unabridged*, Volume 2, p. 1148. (Chicago: G. and C. Merriam and Co. 1966.

[13] The term cohort comes from the latin word for one of the ten divisions of a Roman legion. It is used in demographic research to represent a group of individuals with a common statistical factor such as age.

each measure its share in the sum of the econometric estimates of the output-related cost elasticities.

Summary input price and quantity indexes can also be computed. We might, for example, compare the quantities of OM&A inputs used by a subject utility to those of a cohort group using an index that involves weighted averages of the amounts of labour and non-labor OM&A inputs used. In the construction of input quantity indexes it is customary to use the corresponding cost shares to calculate weights.

Cost Indexes

Cost indexes are used to make cost comparisons. A simple example is the ratio of the cost of a subject utility to the mean cost of a sample of utilities. The costs incurred by a utility were shown in Section 2.2 above to depend on various external business conditions and on its operating efficiency. Suppose, then, that we compare the cost of a utility to the mean for a sample of utilities. We show in the Appendix that such comparisons are likely to reveal how the cost efficiency of the utility compares to the norm for the sample to the extent that the business conditions of the subject utility are similar to those of the sample.

Statistical clustering analysis can be used to develop cohorts that face similar business conditions. This can in principle be based on the results of econometric research. Suppose, for example, that we estimate the coefficients of a cost model econometrically. We can use the coefficient estimates to develop a criterion function that considers the success of alternative cohort groups in gathering companies with similar values for the business conditions that are included in the model. The weighting of the comparisons for the individual explanatory variables reflects what has been learned about their relative importance as cost drivers.

Unit Cost Indexes

A unit cost index is the ratio of a cost index to an output quantity index. It is used to make productivity comparisons. Unit cost indexes can be viewed as comparisons of the costs incurred by companies which control for differences in their operating scale. The output quantity indexes used to construct unit cost indexes can in principle summarize comparisons in several output quantities.

Productivity Indexes

A productivity index is the ratio of an output quantity index to an input quantity index . It is used to make productivity comparisons. The input and output quantity indexes used to construct productivity indexes can in principle summarize comparisons in multiple quantities. An index that compares productivity in the use of more than one input can be called a multifactor productivity (MFP) index. MFP indexes are especially useful in considering efficiency in the use of broader input groups that encompass important substitution opportunities. To illustrate this point, consider the case of a company that uses a lot of in-house labor and very little outsourced services. Such a company is likely to have relatively low labour productivity and relatively high other OM&A input productivity. An MFP index for OM&A inputs sheds light on how things balance out.

Productivity indexes can be viewed as comparisons of the costs incurred by companies which control for differences between the companies in the input prices that they pay as well as differences in their operating scales. They are therefore generally superior to unit cost indexes as measures of the efficiency with which companies use inputs. Despite these advantages, productivity indexes do not control for all of the cost drivers that are thought to explain variations in distributor cost. As we have seen, cost can be a function of miscellaneous business conditions as well as input prices and output quantities.

Statistical Tests of Efficiency Hypotheses

Statistical tests can be developed for efficiency hypotheses when indexes are used in benchmarking. When using cost indexes, for example, it is possible to construct confidence intervals that indicate, for each LDC in a cohort, the full range of costs that may conform to an average efficiency standard at a certain level of confidence. An LDC may be deemed to have an anomalous cost performance if its cost exceeds the upper bound of the interval.

3. Use of Benchmarking in Regulation

Benchmarking has in recent years found growing use in utility regulation. It has been used in some jurisdictions to help establish initial rates and the rate adjustment mechanisms of multi-year regulatory plans. Some plans involve automatic rate adjustments based on ongoing benchmark comparisons.

In this section, we address some important issues that are encountered when benchmarking is used in regulation. We first consider the role of benchmarking in regulation. We then discuss some general criteria for the selection of benchmarking methods used in regulation.

3.1 Role of Benchmarking in Regulation

A major attraction of benchmarking for regulators is the opportunity to economize on regulatory cost. Inputs used in regulation include the labour, office space, and equipment that are required by regulators, utilities, and stakeholders to review rate applications. The labour cost includes the opportunity cost of diverting the attention of senior utility management away from the basic business. The human capital investment required to undertake traditional cost of service regulation competently is substantial. Jurisdictions that are facing large increases in the scale and scope of regulation therefore confront daunting startup costs if traditional methods are used. This naturally increases the appeal of alternative and more streamlined approaches to regulation.

Benchmarking may be viewed as a new technology for reviewing rate applications. Its "active ingredients" include, as we have seen, samples of data on utility operations and theoretical and empirical tools that can be combined to create performance comparisons. These can help to contain growth in the cost of regulation if they substitute to some degree for traditional prudence reviews.

While the potential cost savings from benchmarking are palpable, it is important to remember that regulators, like utilities, are subject to quality standards. In most jurisdictions, rates are expected by law to satisfy a just and reasonable standard. While the exact definition of this standard varies across jurisdictions, it usually concerns the ability of rates to collect the prudently incurred cost of service. Rates above or below this standard are unfair to customers or shareholders, respectively. Rates that fluctuate around this standard can raise the cost of utility operation by raising utility operating risk.

In considering the benchmarking option, it follows that regulators must consider the impact of its adoption on the *quality* of rate decisions as well as the impact on cost. Benchmarking may not be desirable on balance if the quality of the resultant decisions is markedly below the quality of decisions that would be rendered using traditional regulation. The decision to use benchmarking in regulation is in this way similar to that of an LDC that, considering the adoption of an innovation in power delivery technology, must weigh its impact on reliability as well as its impact on cost.

3.2 General Criteria for Method Selection

A number of statistical benchmarking methods are available for use in regulation. In this section we provide some general criteria for selecting a method. Concepts from statistics are used to aid reasoning. Specifically, we treat alternative benchmarking methods as means to predict the true value of a benchmark that represents a certain performance standard. We might, for example, consider the ability of a method to generate a benchmark value that reflects an average level of operating efficiency. The benchmark produced by each method is then a random variable that is drawn from a probability distribution with certain characteristics.

Accuracy

One criterion that is obviously important in choosing a benchmarking method is accuracy. A method is accurate to the extent that it generates the true benchmark. For example, an accurate benchmarking method applied to an average performance standard would correctly identify the value of the performance variable that would be achieved by a company of average efficiency.

The accuracy criterion can be usefully decomposed into two subcriteria: bias and variance. A method is unbiased to the extent that it is *expected* to generate the true benchmark in repeated applications even if it does not due so in every instance. An unbiased method for estimating the cost of an average performer might overestimate it on some occasions and underestimate it on others but would generate estimates equal to the true benchmark on average.   One example of a biased method is one that tends to establish a cost benchmark that is lower and hence more difficult to achieve *for any company* than the true benchmark. Another is a method that tends to generate an excessively challenging benchmark for *companies facing certain business conditions*. Amongst unbiased methods, we desire a method that generates benchmarks that vary as little as possible around the true benchmark.

The concepts of bias and variance are illustrated in Figures 1 and 2 below. In both figures, we treat the benchmarks generated by alternative methods as random variables with values drawn from probability distributions that can be represented graphically as familiar "bell curves." The high part of each curve indicates the range of benchmark values that is likely to occur most frequently. The curves reach their peak at the benchmark value that is expected in repeated applications. This is not necessarily the same as the true benchmark value.

Figure 1

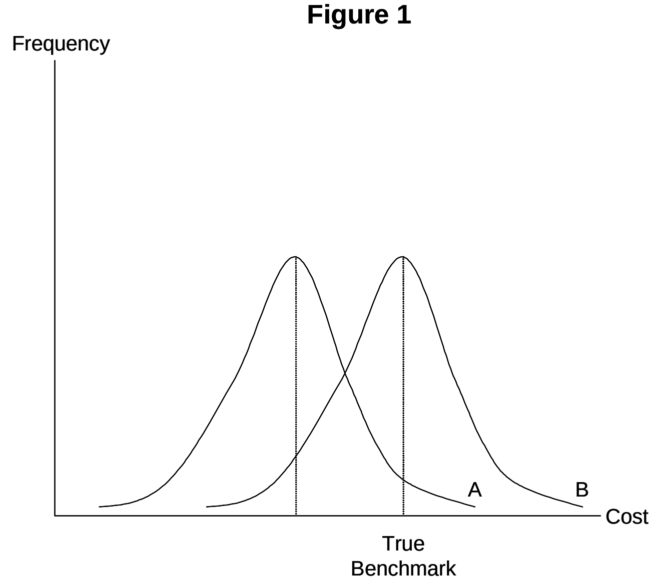
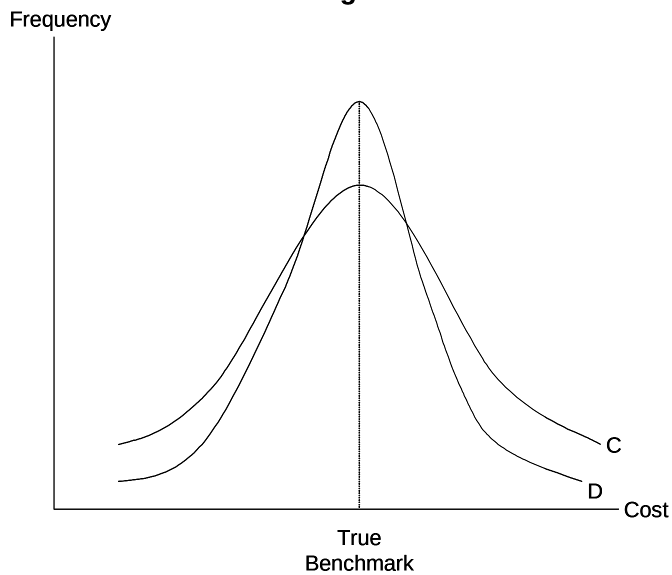


Figure 2



In Figure 1, the curves for two benchmarking methods, A and B, are presented. The curves for each of these methods center upon the expected benchmarking value for the method. The curves differ only in the expected benchmarking value. It can be seen that in the case of method B the expected benchmarking value is the same as the true value. Thus, method B is unbiased. Method A is biased since its expected benchmark value is lower (and more challenging) for the company than the true value.

Figure 2 depicts the probability distributions for methods C and D. It can be seen that both methods are unbiased. However, method D has a lower variance than method C and is therefore more accurate.

The accuracy criterion is important in method selection because of its implications for risk and fairness. A biased method can be unfair to the interests of utilities or consumers. High variance methods increase utility operating risk even when they are unbiased. They thereby raise the cost of obtaining funds in the marketplace.

Benchmarking Cost

The cost of benchmarking is another relevant consideration in method selection. Methods are generally more costly to the extent that they are more accurate. Simply put, accurate benchmarking of complex phenomena requires complex methods. Complex methods are more costly to develop and implement than simple methods and are also more costly for stakeholders to review. The cost of achieving a given level of accuracy will be greater to the extent that readily available data are deficient in quantity or quality. It will also depend on the current state of the benchmarking art.

Striking a Balance

In choosing a benchmarking method a reasonable balance must be struck between accuracy and cost. Since traditional regulation is costly, even complex benchmarking methods have the potential to reduce net costs. However, it is also important to realize that the amounts of money at stake in the regulatory arena are generally far in excess of the cost of regulation. A bad benchmarking method that generates bad appraisals can violate the just and reasonable standard and, by raising operating risk, materially offset any net cost savings in the regulatory process.

The system of jurisprudence in western civilization provides an interesting perspective on the balance between the accuracy of decisions and the cost of arriving at them. The process is clearly a costly one. However, society evidently has weighed these costs against the benefits of fairness and reduced risk that our court systems provide.

One sensible conclusion that may be drawn from this discussion is that a fairly high level of accuracy is desirable when benchmarking is used in the regulatory arena. The cost of a benchmarking study that can attain such accuracy can be non-negligible. This conclusion should not be misinterpreted to suggest that there always exists some benchmarking method that is optimal. No benchmarking may be the desirable strategy when a reasonable degree of accuracy cannot be attained.

3.3 The Use of Benchmarking Results

Our discussion also leads to the conclusion that the use of benchmarking results matters as much as the choice of a benchmarking method. To the extent that there are concerns about the accuracy of benchmarking, its use in ratemaking should be more limited. For example, results might be used to screen utilities for more traditional prudence reviews rather than used mechanistically to set rates.

4. The Power Distribution Business

In this section we briefly discuss some features of the power distribution business that are important in the appraisal of benchmarking work**.** We consider first the local power delivery business. There follows a discussion of customer care services.

4.1 Local Power Delivery

LDCs receive power in bulk from points on high-voltage transmission grids and deliver it to consumers. Receipt commonly occurs at substations, where voltage is reduced from transmission to distribution levels. Power is in most cases delivered to end users at the voltage at which it is consumed. Distributors undertake any further reduction in voltage that is required. Voltage levels are higher for many industrial customers than for residences.

Continuous use of electric power is essential to the functioning of modern homes and businesses. Power storage and self-delivery are, additionally, generally not cost competitive with power produced in bulk and delivered by utilities. It follows from these demand attributes that the vast majority of residences and business establishments want local delivery capability to be available continuously.

The technology for providing reliable service requires a network in the sense of a system that is physically connected to the premises of end users. Delivery is achieved via conductors that are usually held above ground but pass underground in some areas through conduits. Important facilities used in distribution include conductors, line transformers, station equipment, poles and conduits, meters, vehicles, storage areas, office buildings, and information technology (IT) inputs such as computer hardware and software. LDCs commonly construct, operate, and maintain such facilities but may outsource certain functions.

The character of power demand is also such that interruptions in power delivery are costly to customers. LDCs are, therefore, expected to deliver power reliably and to establish service quickly for new customers. Systems with overhead lines are subject to disruption from violent weather conditions. These conditions are unpredictable. When disruptions occur, LDCs are expected to restore service promptly. End use electrical equipment is designed to operate within a narrow range of voltage levels. The stability of power voltage is thus another important dimension of distribution service quality.

Certain expenditures by LDCs have a periodic character. Line maintenance activities such as tree trimming do not, for example, have to be undertaken at the same level each year. Distributors make capital investments in response to output growth. These investments, once made, may not require replacement for 30-50 years. The amount and cost of capital on hand in a particular year therefore depend greatly on the historic pattern of output growth. A distributor that has experienced slow customer growth in recent years is more likely to have a more depreciated system.

The workload of an LDC has several dimensions. Econometric cost research by PEG economists and many others around the world has suggested that the list of potentially relevant output variables includes the number of customers served, peak demand, the delivery volume, and the distance that power is transported. The distance transported is commonly measured by line length.

Benchmarking is complicated, especially in international comparisons, by differences in the services that distributors undertake and/or classify as distribution facilities. Activities that may or may not be provided by each LDC in a large sample include the following:

- Voltage step down from transmission or subtransmission to primary distribution levels
- Medium voltage transportation
- Connections to end users
- Metering and billing.

Research has also highlighted miscellaneous other inconsistencies in the manner in which data are reported by distributors. These problems are especially marked where utilities have some discretion in cost reporting due to lax reporting guidelines and/or the inherent arbitrariness of cost allocations. Problem areas include the following.

- Capitalization of O&M expenses
- Defining costs as billings and collection or customer service & information.
- Categorizing customers as commercial or industrial

- Identifying administrative and general expenses.

Cost research by PEG and others has identified a wide range of additional business conditions that are statistically significant drivers of Wires and Interconnections cost. These include the following:

- Reliability and other dimensions of service quality
- System age
- Extent of forestation
- Winter weather severity
- Provision of gas distribution service

4.2 Customer Services

The customer care unit of an LDC is responsible for revenue cycle and other customer contact responsibilities. Revenue cycle services include meter reading, billing, and collection. Other customer contact responsibilities include the exchange of information with customers. This includes requests for changes in service.

The provision of customer care services requires capital, labor, and other operating inputs. Technological change has been rapid in the business in recent years. For example, software systems are available to manage customer information and prepare invoices. With the advent of the internet, the technology also exists for customers to access account information, pay bills, and change service requests electronically. There are extensive opportunities to outsource customer care tasks.

Because of these changes, customer care technology has become more capital intensive and software has become an important class of capital inputs. The cost effectiveness of software is generally greater the larger is the scale of a distributor's operations. That is because the chief cost in the use of software is its initial purchase and/or development. The cost incurred to serve an additional customer once a particular system is up and running is relatively modest. Our analysis also suggests that major changes in the package of customer care services, such as those occasioned by the introduction of retail competition, can involve sizable short run costs due to investments in new software systems.

Econometric research on customer service costs is not well advanced. We have found in our research that customer care cost depends on system extensiveness as well as the number of customers served. Generally speaking, a system with low customer density may be expected to have higher cost per customer. The extent of DSM activity and the number of gas customers served are also statistically significant cost drivers.

Additional variables that may have an impact on customer care costs include the following:

- Mix of large and small volume customers
- Retail competition
- Quality of customer care services
- Bilingual service territory
- Pace of customer turnover

4.3 Functional Form

Our econometric research on power distribution and customer care costs suggests that the relationships between costs and business condition variables are often highly non-linear. This argues in favor of the use of flexible functional forms such as the translog when these can be supported by the available data.

5. An Appraisal of the Camfield Report

5.1. Summary of the Camfield Method

The general method Mr. Camfield detailed in his report merits brief summary at the start of our appraisal.

1. A number of cost performance variables would be chosen as the subject of a benchmarking investigation.
2. For each such variable, cost drivers would be identified econometrically. In such a study, cost models would be developed in which each cost performance variable is a function of certain business condition variables (*e.g.* the number of customers served) that measure cost drivers. The coefficients of the model would determine the sensitivity of cost to the values of these variables. These coefficients would be estimated statistically using historical data on the costs incurred by Ontario LDCs and the business conditions that they faced.
3. The coefficient estimates obtained from the econometric work would be employed in a statistical clustering analysis. This analysis would identify, for each cost performance variable, cohorts of LDCs with relatively similar values for the measured business conditions.
4. The costs of each LDC would be compared to the averages for the cohorts in which it is placed.
5. Additional performance variables, called comparators, would be chosen for the individual cohorts. This would permit the calculation of "comparative diagnostics."
6. The cost comparisons, together with the comparative diagnostics, would be used to identify utilities with anomalously high costs.

5.2 Cost Performance Variables

Mr. Camfield discusses in his report the use of the C&C method to appraise the following cost performance variables:

- Wires and Interconnections opex
- Wires and Interconnections capital

- Billings and Collections opex
- Billings and Collections capital
- Customer Service opex
- Customer Service capital
- Administrative opex
- Administrative capital

This list raises several issues that the Board should carefully consider. One is that Camfield is proposing separate consideration of two general groups of inputs, opex and capital, that are in many cases substitutes. A firm may, for example, have high Wires and Interconnection opex because it has a relatively old distribution system. There is then a danger that a finding of high opex could be taken "out of context" and lead to the false conclusion of cost anomalousness. Camfield acknowledges the general problem in stating on p. 24 of his report that operating inputs "are generally long-run substitutes for capital particularly as capital ages."

It is clearly desirable for the benchmarking methodology to reduce the chances of such false judgments. The problem might be mitigated to some degree by considering the results of capital cost comparisons in making final decisions about opex cost anomalies. However, Camfield has not provided a framework for properly balancing such considerations. An alternative and more sensible approach is to use restricted cost functions, which consider the other inputs in use, as the theoretical foundation for the econometric cost models.

Mr. Camfield does not explicitly recognize the relevance of restricted cost functions in his theoretical discussion. On p. 20 of his report he states, to the contrary, that "the equations used in the analysis can be thought of as representing the *demands* for various inputs." Demand functions are different from restricted cost functions and do not include "other input" variables. As discussed further below, however, Camfield does use a restricted cost approach in the specification of his Wires and Interconnections opex model. This general approach should be extended to the other opex equations as well.

The breakout of opex and capital costs also raises the issue that firms have some discretion in the classification of certain expenses as capital or opex. Clear cost classification guidelines may be helpful in this regard but may not be sufficient. An additional sensible measure would be for each LDC to report the percentage of the costs that could be classified as operating expenses that it has in fact capitalized. Such percentages are often reported by Canadian utilities in their rate filings. The percentages may prove useful as cost model explanatory variables.

A third concern is that a detailed breakdown of costs such as Camfield proposes can involve the allocations of certain common costs. The allocation of common costs is essentially arbitrary. Firms that allocate an unusually high percentage of common costs to one business unit rather than another may expose themselves to the risk of a cost anomaly finding,

This is particularly evident in the proposed breakdown of customer care costs into billing and collections and customer information.[14] These two services can involve a number of common inputs that include personnel and software. Larger companies like Hydro One may, for instance, use middleware that are useful in the provision of both services. This problem can clearly be alleviated by treating customer care services on a consolidated basis. Consolidated treatment has the further substantial advantage that this is the way that the LDCs have been reporting these costs for the last two years.[15]

The idea of benchmarking capital cost merits extended discussion. Camfield's resolve to benchmark capital cost isn't clear. He states on p. 10 of his report that "relative cost efficiency has investment and O&M dimensions." He goes on to present in his Proof of Concept section results for an econometric cost model for distribution gross fixed assets. The hard copy of his January 6 presentation, on the other hand, contains the remark that "capital, however defined, will likely play only a limited role in the C&C mechanism".

Camfield acknowledges some of the obstacles to accurate capital cost benchmarking that we discussed in Section 2.5 above. On p. 9, for instance, he observes that

> differences in load growth within existing service territories ... has a direct impact on cost differences. Distribution facilities and equipment have

[14] Companies may also differ in their propensities to allocate costs between the administrative and general function and other business functions.
[15] It should also be noted that LDCs have not been separately reporting the capital costs of customer care services.

> exceptionally long lives. For distribution organizations that have little growth over years [sic], the capital base (rate base) may reflect a concentration of early vintage investment, which tends to reduce cost stated in embedded cost terms.[16]

It is not clear how Camfield proposes to finesse this problem. On p. 14 of his report he states that "we intend to utilize perpetual inventory refunds to value the capital stock in the followup analysis." On p. 22 of his January presentation he states that "if possible, real capital stock will be constructed and used in lieu of an accounted-based [sic] measure." In the January conference call, Camfield commented that if a perpetual inventory approach to capital costing was used, it would probably *not* involve the collection of any historical data on plant additions and retirements.

In a footnote on p. 14 of his report, Camfield states that an alternative and simpler approach to capital cost benchmarking may be used.

> The real capital stock as an indicator of the physical quantity of capital measured in dollars may be inferred through the application of heuristic methods. For the near term deliverables and absent the necessary historical data, ad hoc approaches based on various notions of growth may be used to make adjustments to the accounting measures of capital. This estimation procedure can hopefully obtain a satisfactory measure of the desired capital stock.

Camfield has not explained what is meant by "ad hoc approaches based on various notions of growth."

This discussion raises concerns on several grounds. Recall from our discussion of capital cost in Section 2.5 above that the accuracy of a replacement valuation of the capital stock depends greatly on the distance of the benchmark year from the present year. Assuming that good historical plant addition data are available, it is desirable to have a benchmark year that is a far as possible in the past.

A capital cost study that uses 2004 as a benchmark year is far from optimal. The alternative, of course, is to gather the data needed for a substantially earlier benchmark year. However, this would be difficult for many Ontario LDCs. The many mergers and

[16] Similar thoughts are expressed on p. 14.

acquisitions that have recently occurred amongst the LDCs is a formidable complication. Another problem, discussed in the January conference call, is that some LDCs include in their rate bases certain contributions in aid of construction made prior to 1999.

Even if respectable capital cost measures could be prepared for a large number of LDCs, there remains the consideration that such measures do not fully solve the problem of different historical patterns of output growth. System age variables would have to be developed for use in the capital cost equations. The collection of data needed to construct such variables may be difficult. In research using U.S. data, we have found that system age variables can be statistically significant. However, our review of empirical research on power distribution cost around the world suggests that experience with such variables is extremely limited.

Our comments above on the relationship between benchmarking, operating risk, and the cost of acquiring funds in the marketplace should also be considered. If the total cost of capital is benchmarked, LDCs are effectively placed at risk for the recovery of their past investments. Even if capital cost benchmarking has limited uses in the 2006 rate setting, the investment community would rationally weigh what *future* developments in OEB benchmarking might place recovery of capital cost at risk.

Many of these problems have been encountered by regulators in other jurisdictions. This helps to explain why statistical benchmarking of capital cost has been much less commonly used by regulators than statistical benchmarking of opex. Our discussion leads to the conclusion that the Board should adopt the same strategy and concentrate on opex benchmarking for the 2006 EDR update if the quality of the supportive data improves.

5.3 Other Data Collection Issues

A number of other data collection issues merit brief comment.

1. Camfield correctly notes that demand-side management (DSM) programs are a potentially important category of customer service expenses. Levels of DSM effort may, furthermore, vary considerably between LDCs now or in the future. This situation complicates accurate benchmarking even if customer service expenses are separately considered, as Camfield proposes. LDCs should, accordingly, be directed

to separately state their DSM expenses. The delivery volumes saved due to each LDC's DSM programs would also be helpful but can be costly to estimate accurately.

2. Camfield is quite right to recommend that IT costs be carefully reported. The measurement of IT costs is a real problem with U.S. FERC Form 1 data. It is desirable to report IT capital costs separately. However, the allocation of these costs to business units can be problematic.
3. Camfield is reasonably attentive to the gathering of data on the special challenges of rural operation. The idea of a Canadian shield variable is a good one. His proposal for a North-South variable, however, may merit reconsideration. Alternative ideas include measures of winter weather severity and of the extent of forestation in a service territory.
4. Camfield recommends the collection of data on the circuit miles of distribution lines. Line lengths may well be the best measures of system extensiveness that are readily available. It is not clear, however, whether *structure* miles or *circuit* miles are best for this use. Accordingly, data on structure miles as well as circuit miles should be collected. It is also desirable for LDCs to separately report the length of medium voltage lines that they own since these can be more costly to operate and maintain.
5. Camfield is also on the right track in recommending the collection of data on transformer capacity. Care must be taken, however, in selecting transformer capacity measures. In particular, it is desirable to measure the capacity to step down voltage to primary levels and not just the number of transformers.
6. Camfield is generally much less attentive to gathering data that are pertinent to the special challenges of customer service cost. For example, he proposes only two customer-related Z variables: customer turnover and service terminations. A more thorough review of customer service cost drivers must, accordingly, be undertaken before any new data request is finalized.

5.4 Econometric Work

Camfield presents details of regression work for four cost performance variables in his report:

- Wires and Interconnections gross assets

- Wires and Interconnections opex
- Billings and Collections opex
- Administrative expense

The explanatory power of the models is generally high, as indicated by the fact that all models have an adjusted R-squared statistic in excess of 0.800. F tests in all cases confirmed that the models have statistically significant explanatory power. Most variables included in the models have statistically significant and sensibly signed coefficient estimates.

Wires and Interconnections Gross Assets

The reported gross asset equation included two output quantity variables – customers and line miles – and some additional Z variables (*e.g.* total transformers, share of distribution line underground, share of transformers at transmission level). No variables measuring system age or the amount of opex were used. The choice of gross rather than net asset value is controversial.

Wires and Interconnections Opex

This equation contained two output variables (total customers and total transformers), an input price variable (average compensation), and one Z variable (share of distribution lines underground). It also contained two variables pertaining to the amount of capital used: gross fixed assets and accumulated depreciation squared. This equation is therefore a restricted cost function and not a demand function. The positive estimate on the accumulated depreciation coefficient may indicate the impact of system age on opex.

Billings and Collections Expenses

The reported equation includes a single output quantity variable: the number of general service customers. It is not clear how a general service customer is defined. Neither is it clear whether the miles of distribution line was considered as an output variable. There is one marginally significant Z variable: the service territory population. The urbanization variable coefficient is statistically insignificant,

Administrative Expenses

The administrative expenses equation does not include any output quantity variables, input prices, or Z variables. There are three input quantity variables: gross asset value, total operating expenses, and billing expenses. The positive coefficient estimates for these variables suggest that, in the absence of output quantity variables, these variables served as proxies for operating scale.

Functional Forms

Results are presented for models with both linear and double log forms. Camfield discusses functional forms but does not place sufficient emphasis on the importance of *flexibility* in his discussion. He does, however, use a squared term in lieu of a linear term in one regression. It is desirable to use more flexible functional forms if these are supported by the data and are not achieved at the expense of recognizing important cost drivers.

Sample Issues

The sample used in Camfield's regression work consisted of a panel of data for the 2002 and 2003 period. The total number of observations ranged from 152 for Wires and Interconnections opex to 171 for Billings and Collections opex. In the January conference call, Camfield suggested that final results would probably be based *solely* on 2004 data. The suggested reason is that only the data for this year would rise to the quality standard needed for the research. It is important to note that a sample half the size of the sample used in the Proof of Concept (*i.e.* one year of operating data rather than two) would make it considerably more difficult to identify statistically significant cost drivers.

Sample variation is another important consideration. We noted above that variation enhances the likelihood of identifying statistically significant cost drivers. Variation in operating scale is substantial in the sample. For other cost drivers, however, variation may be considerable but still not great enough to produce statistically significant coefficient estimates. An example might be measures of winter weather severity. Weather in northern Ontario might be cold enough to raise operating costs materially, but the variation in weather severity in the sample may not be great enough to recognize this effect.

Criteria for Model Development

Camfield does not provide in the report clear principles for model specification. He does seem to believe that included variables should have statistically significant coefficients. However, other principles merit enunciation. In particular:

- The output specification should be subject to special attention and be the best available. For example, the full range of output variables should be considered in every cost model since line miles, as a measure of system extensiveness, may affect customer service and administrative expenses as well as wires and interconnections expenses.
- No variable should be excluded from the model that is a plausible cost driver and has a statistically significant and sensibly signed coefficient.

Camfield's Conclusions

Camfield repeatedly notes the statistical significance of the models that he has developed. On p. 28 of the report, for example, he comments that "we have found that significant relationships exist among the reported information". It is important to observe, however, that high model explanatory power is not surprising in a sample of Ontario LDC data. After all, operating scale is known to be an important cost driver and varies greatly amongst the firms in the sample.

The real question is whether econometric cost research can provide a satisfactory basis for the identification of good cohort groups. Given the multicollinearity that exists amongst candidate scale variables and certain other variables in the sample, any of variables will produce a high R squared statistic. In this environment, accurate benchmarking requires success in identifying the *relative* contributions of different scale measures.

To illustrate this point, suppose that the number of customers served and line length have substantial but equal impact on Wires and Interconnections opex. Suppose, additionally, that the number of customers served and line length are correlated. In that event, a model that contains *only* the number of customers served may have high explanatory power yet lead, incorrectly, to the result that between two LDCs with identical cost efficiency and the same number of customers, the LDC with greater line length is an inferior cost performer.

5.5 Statistical Clustering Analysis

Camfield's report provides no details concerning the statistical clustering analysis. Very little additional detail was added in the January conference call. It is therefore difficult to speak for or against the specific method used.

Some general comments concerning the clustering analysis may nonetheless be ventured.

1. Statistics should be reported on the similarity of the business conditions facing firms in the chosen cohorts. Presumably, some cohorts will have greater similarity than others. This kind of calculation should be produced automatically by the statistical clustering analysis.
2. Statistical clustering analysis helps to identify cohorts with *relatively* similar business conditions but will not necessarily produce cohorts with *sufficiently* similar conditions. Camfield should comment on whether the degree of similarity in each chosen cohort is satisfactory.
3. Measures of variability (*e.g.* standard deviation) of the costs of companies in each cohort should be calculated and reported.
4. Consideration should also be paid to establishing a standard for the inclusion of a company in the comparators and cohorts process. For example, what value of a summary measure of deviation from the sample means of the included business conditions is unacceptable?
5. Our discussion of statistical clustering analysis above suggests that in selecting cohorts there is a tradeoff between business condition similarity and the size of the cohort. Camfield should comment on this important issue.

5.6 Selection of Comparators

Camfield does not provide general principles for the selection of the comparators used for comparative diagnostics. In his Proof of Concept section, he provides the following set of comparators for Wires and Interconnection opex:

- Two simple unit cost measures (opex/kWh and opex/customer)
- Two simple productivity measures (FTE/MWh and FTE/customer)
- One labor price measure (average employee compensation).

Additional comparators, mentioned in his January presentation, include the following:

- Opex / km of conductor

It is not clear whether his mentions of these variables constitute recommendations or, instead, merely illustrations of the possibilities.

Our discussion of indexing methods provides the foundation for the following comments on these comparators.

1. The unit cost and productivity measures are simple. For example, each measure involves only a single output variable. The productivity measures involve only one input – labour.
2. Measures with single output measures can produce conflicting results depending on which output measure is used. An LDC serving a sparsely populated rural area will, for example, look much better on a dollars per line length basis than on a dollars per customer basis. High cost per customer is therefore not by itself an indication of inefficiency. An LDC serving an urban area is, similarly, apt to have relatively high cost per unit of line length. These problems can be avoided if unit cost and productivity indexes are used that feature multiple category output quantity indexes with cost elasticity weights. The weights can be drawn from the econometric work.
3. As for labour productivity measures, we have already noted that these are unsatisfactory measures of labour cost management. One material problem is the lack of control for the amount of other OM&A inputs used. Multifactor productivity indexes encompassing all OM&A inputs are better measures of OM&A cost management.
4. There is substantial overlap between the measures. Unit cost, for instance, depends on both labour productivity and labour expense per employee.

5. Consideration should also be paid to comparators that can facilitate decisions concerning anomalousness but are not performance variables. One example would be measures of the similarity of the measured business conditions of each firm to the corresponding mean values for the sample. Individual measures and a summary measure would both be useful.
6. If multiple comparators are used, how do we weight the results? Formal rules may be unduly restrictive. Absent *any* rules, however, the Board and intervenors may be freed to jump to the wrong conclusions based on highly partial cost performance measures.
7. Camfield recognizes this danger in stating on p. 28 of his report that “the test reveals that not necessarily does a high cost indicator, which are [sic] narrow definitions of cost, reveal [sic] high costs for cost area [sic] (*e.g.* operating expenses) or the unbundled services as a whole.
8. Camfield states on p. 28 that “This Step 4 test demonstrates that for various cost indicators (Comparative Diagnostics), comparisons can be performed and are useful”. This statement is true but says little. Diagnostics can be useful but his work suggests that the selection of an appropriate group of comparators is difficult and controversial. Useful is not the same as optimal.

5.7 Identification of Anomalies

Camfield has not been clear on how information generated by the C&C process would or should be used to identify anomalies. Apparently, a cost above the mean for a cohort is more likely to be deemed anomalous. But how extreme does a value have to be? And how will the comparative diagnostic information be used in the decision?

There is, additionally, little discussion in the report or the January presentation of the role of uncertainty in benchmarking research. Anytime benchmarking is done, there is uncertainty as to whether performance is being accurately measured. This uncertainty takes several forms. In a sample of results for five LDCs, for instance, average cost can be a volatile measure of operating performance even if the cohort is based on statistical clustering analysis. After all, the measured business conditions of LDCs in the cohort are similar but not the same. Additionally, the econometric model will inevitably be an incomplete representation of cost drivers and their impacts. Note also that variables like opex will fluctuate from year to year with such factors as ice storms and the timing of tree trimming projects.

The certainty that a company differs from a performance standard is reduced to the extent that

- the explanatory power of the supporting cost model is low
- the values of measured business conditions are dissimilar within the cohort
- the number of peers is small
- the number of years over which results are averaged is small

It follows that it is desirable to use multiple years of data in a cost performance comparison. The costs of individual utilities might, for example, be compared to the cohort means for two or three years rather than one year. Additionally, statistical tests can be developed for the hypothesis that the cost performance of an individual utility differs from the average for the cohort. Such tests should be reported even if they are not used mechanistically to make judgments about anomalousness.

5.8 Use of the Results

The merits of undertaking further C&C work depend on the uses to which it will be put. Camfield states on p. 5 of his report that

> the purpose of the Comparators and Cohorts mechanism for 2006 is to serve as a tool to screen the rate applications of the LDCs, and to highlight cost anomalies for consideration by Board staff.

Given the many uncertainties that exist concerning the accuracy of the benchmarking exercise, this limited use of the benchmarking results is a good idea. Camfield and the Board should, additionally, acknowledge that the methodology is highly experimental and may generate certain partial results that do not by themselves suggest operating inefficiency.

The experimental character of the methodology probably precludes the use of evidence of superior performance to reward companies. Our incentive power research suggests, however, that such rewards can serve the public interest. The Board can leave the door open to this idea by acknowledging LDCs that appear to be superior performers.

5.9 Role of Benchmarking in Regulation

Camfield's more general discussion of the role of benchmarking in regulation focuses chiefly on the issue of regulatory cost. He states on p. 5 of his report that

> The mechanism, should it prove successful, can provide Board staff with the means to realize substantial gains in regulatory process efficiency and effectiveness. Process efficiency means that the Comparators and Cohorts mechanism is a cost effective vehicle to help the Board and its staff review, process, and judge the numerous rate applications that will require simultaneous consideration in the second half of 2005...It is not, however, in the overall interest of the Province of Ontario and its citizens to impose a burdensome Comparators and Cohorts filing requirement on the LDCs, such that the total costs of regulation and governance ... rise.

This discussion does not give balanced consideration to the *quality* of the Board's assessments. As discussed above, the accuracy of benchmarking is an important determinant of its net contribution to the regulatory process. Inaccurate methods can be unfair and, by increasing operating risk, raise the cost of utility operation.

5.10 Camfield's Conclusions

Camfield states on p. 22 regarding his empirical research that

> We have not found that the reported data are dominated by reporting errors and are of little value and that the LDCs in Ontario are characterized with unique attributes that could not be captured. In contrast, these preliminary analyses reveal systematic relationships between costs and RHS variables, and the relationships appear to be intuitively plausible in most cases, though not all.

He states on 29 that "our studies lead us to find that the Comparators and Cohorts mechanism is feasible for the task as described and can be developed and implemented to practical advantage." This core conclusion seems to be based almost entirely on the fact that it was possible to develop some econometric models with high explanatory power and several significant and plausibly signed cost drivers.

Our analysis of the research suggests a more cautious conclusion. We find that the results obtained to date do not by themselves provide sufficient support for proceeding on the course that has been recommended by Camfield. He has not provided a proof of the C&C concept. While he properly acknowledges deficiencies in the data, the collection of better data will not by itself make the C&C approach acceptable. The methodology should, in fact. be changed in several ways if additional work is to be commissioned. Important dimensions of this "mid-course correction" include the following:

- Exclusion of capital cost as a cost performance variable
- Consolidated treatment of customer care expenses
- Use of restricted cost functions to guide opex model design
- Reporting of key clustering analysis statistics
- Reconsideration of the comparators
- Development of statistical tests of efficiency hypotheses to more formally integrate considerations of uncertainty.

Camfield and the Board should, additionally, make the following acknowledgements.

- Econometric models used in statistical clustering analysis should be specified using a clear set of rules, and do the best possible job of explaining variation in the cost data.
- Some comparators considered will not be stand-alone measures of operating efficiency.
- Benchmarking results contain a high degree of uncertainty.
- Inaccurate benchmarking methods can lead to assessments that are unfair to LDCs and raise their cost by increasing their operating risk. This cost should ultimately be born by customers.

Appendix

A.1 Cost Drivers and Econometric Cost Models

Some readers will prefer the following mathematical presentation of the cost driver discussion. Suppose that the actual cost of a utility is the product of minimum cost and an efficiency factor. The natural log (ln) of actual cost is then the *sum* of the natural logs of minimum cost and the efficiency factor:

$$\ln C = \ln C^* + \ln inefficiency. \quad [1]$$

Under certain reasonable assumptions, cost functions exist that relate the minimum cost of an enterprise to quantifiable business conditions in its service territory. A *total* cost function has the following general form

$$C^* = C(\boldsymbol{W}, \boldsymbol{Y}, \boldsymbol{Z}). \quad [2]$$

Here the minimum total cost of an enterprise (C) is a function of a vector of input prices ($\boldsymbol{W} = W_1, W_2,\ldots W_J$), a vector of output quantities ($\boldsymbol{Y} = Y_1, Y_2,\ldots Y_I$), and a vector of variables representing miscellaneous other relevant business conditions ($\boldsymbol{Z} = Z_1, Z_2,\ldots Z_M$).

A *restricted* cost function has the following general form:

$$C^{partial\,*} = C^{partial}(\boldsymbol{W}^{\boldsymbol{partial}}, \boldsymbol{Y}, \boldsymbol{X}, \boldsymbol{Z}). \quad [3]$$

Here $C^{partial\,*}$ is the minimum value of some subset of total cost. It is a function of a vector of the prices of inputs in the subset ($\boldsymbol{W}^{\boldsymbol{partial}}$) and a vector of the quantities of other inputs being used ($\boldsymbol{X}^{\boldsymbol{Other}} = {X^{Other}}_2, {X^{Other}}_3,\ldots, {X^{Other}}_N$) by the utility. The $\boldsymbol{Y}$ and $\boldsymbol{Z}$ terms are the same as before.

A.2 Econometric Cost Models

An econometric cost model based on the restricted cost function has the following general form.[17]

$$C = f(\boldsymbol{W}^{\boldsymbol{Included}}, \boldsymbol{Y}^{\boldsymbol{Included}}, \boldsymbol{X}^{\boldsymbol{Included}}, \boldsymbol{Z}^{\boldsymbol{Included}}, u) \times inefficiency. \quad [4]$$

Here $\boldsymbol{W}^{\boldsymbol{Included}}$, $\boldsymbol{Y}^{\boldsymbol{Included}}$, $\boldsymbol{X}^{\boldsymbol{Included}}$ and $\boldsymbol{Z}^{\boldsymbol{Included}}$ are vectors of the *included* business condition variables and u is the error term. It is customary to display the dependent variable on the left-hand side of the equation and the business condition variables that

[17] Opex and other partial cost models are constructed analogously.

influence cost on the right-hand side. For this reason, business condition variables are sometimes called right-hand side (RHS) variables.

Specific forms must be chosen for econometric cost models. In these forms, the sensitivity of cost to the value of each included explanatory variable is determined by coefficients. Here is a simple example of a linear cost model.

$$C_{h,t} = (a_0 + a_1 \cdot Y_{h,t} + a_2 \cdot W_{h,t} + a_3 \cdot Z_{h,t} + u_{h,t}) \cdot inefficiency_{h,t}. \quad [5]$$

Here for each firm h in year t, the variable $Y_{h,,t}$ is an output variable, $W_{h,t}$ is an input price, and $Z_{h,t}$ is a Z variable. The terms a_0, a_1 and a_3 are the model coefficients.

Here is an analogous cost model of *double log* form.

$$\ln C_{h,t} = (a_0 + a_1 \cdot \ln Y_{h,t} + a_2 \cdot \ln W_{h,t} + a_3 \cdot \ln Z_{h,t} + u_{h,t}) + \ln inefficiency_{h,t}. \quad [6]$$

Notice that the dependent variable and all three business condition variables have been logged. This specification has the effect of making the coefficient corresponding to each business condition variable the elasticity of cost with respect to the variable. For example, the a_1 coefficient indicates the elasticity of cost with respect to growth in the output quantity. In a double log model, the elasticities are *constant* in the sense that they are the same for every value of the cost and business condition variables.[18]

The *translog* functional form is widely used in scholarly cost research. Here is an analogous cost function of translog form.

$$\begin{aligned} \ln C_{h,t} = (&a_0 + a_1 \cdot \ln Y_{h,t} + a_2 \cdot \ln W_{h,t} + a_3 \cdot \ln Z_{h,t} + a_4 \cdot \ln Y^2{}_{h,t} \\ &+ a_5 \cdot \ln W^2{}_{h,t} + a_8 \cdot \ln W_{h,t} \cdot \ln Y_{h,t} + u_{h,t}) + \ln efficiency_{h,t}. \end{aligned} \quad [7]$$

This form differs from the double log form in the addition of quadratic and interaction terms. Quadratic terms such as $\ln Y^2{}_{i,t}$ permit the elasticity of cost with respect to each business condition variable to differ with the value of the variable. The elasticity of cost with respect to the output variable may, for example, be lower at low values of line miles than at higher values, where available scale economies have been exhausted. Interaction terms like $\ln W_{i,t} \cdot \ln Y_{i,t}$ permit the elasticity of cost with respect to one RHS variable to depend on the value of another such RHS variable. For example, the elasticity of cost

[18] Cost elasticities are not constant in the *linear* model. The elasticity with respect to the output variable, for instance, has the formula $a_1 \cdot (Y_{h,t} / C_{h,t})$. Notice that the elasticity increases at higher output levels.

with respect to growth in output may depend on the input price. Please notice that, in the interest of model simplification, the Z variables are frequently not translogged.

The translog form is an example of a *flexible* functional form. Such forms can accommodate a greater variety of possible relationships between cost and the business condition variables. A noteworthy disadvantage of the translog form is that it involves many more variables than simpler forms such as the double log. This has limited its use in situations where the data available for model estimation are limited.

A.3 Cost Indexing and Statistical Clustering Analysis

To better appreciate the rationale for statistical clustering analysis, consider first the accuracy of the simple cost comparison $C_{h,t}^{OMA} - \overline{\ln C_t^{OMA}}$ as an efficiency measure. Assuming for simplicity that minimum cost is a double log function of three variables, we find that

$$\begin{aligned}
&\ln C_{h,t}^{OMA} - \overline{\ln C^{OMA}} \\
&= (a_0 + a_1 \cdot \ln Y_{h,t} + a_2 \cdot \ln W_{h,t} + a_3 \cdot \ln Z_{h,t} + u_{h,t}) + \ln efficiency_{h,t} \\
&- (1/H) SUM_h [(a_0 + a_1 \cdot \ln Y_{h,t} + a_2 \cdot \ln W_{h,t} + a_3 \cdot \ln Z_{h,t} + u_{h,t}) + \ln efficiency_{h,t}] \quad [8] \\
&= (a_0 + a_1 \cdot \ln Y_{h,t} + a_2 \cdot \ln W_{h,t} + a_3 \cdot \ln Z_{h,t} + u_{h,t}) + \ln efficiency_{h,t} \\
&- (a_0 + a_1 \cdot \overline{\ln Y_t} + a_2 \cdot \overline{\ln W_t} + a_3 \cdot \overline{\ln Z_t} + \overline{u_{h,t}}) + \overline{\ln efficiency_t}
\end{aligned}$$

Our hope is that this expression equals the measure of operating efficiency, $\ln efficiency_{h,t} - \overline{\ln efficiency_t}$ However, this is true only if

$$0 = a_1 \cdot (\ln Y_{h,t} - \overline{\ln Y_t}) + a_2 \cdot (\ln W_{h,t} - \overline{\ln W_t}) + a_3 \cdot (\ln Z_{h,t} - \overline{\ln Z_t}). \quad [9]$$

It can be seen that the accuracy of a simple cost ratio as an efficiency measure depends greatly on how the business conditions faced by the sampled utilities match up to the business conditions facing the subject utility. One circumstance in which the measure is unbiased is that in which the sample average values of each business condition exactly equal the value faced by the subject utility.

Statistical clustering analysis can be used to develop cohorts that face similar business conditions. This can in principle be based on the results of econometric research. For example, with estimates of the elasticities a_1, a_2, and a_3, we can develop a criterion function that ranks alternative possible cohorts on the basis of the similarity of the business conditions that are included in the econometric cost model. Here is one example of a function that can be used to measure the degree of business condition similarity of a cohort:

$$\sum_h [\hat{a}_1 \cdot (\ln Y_{h,t} - \overline{\ln Y_t})^2 + \hat{a}_2 \cdot (\ln W_{h,t} - \overline{\ln W_t})^2 + \hat{a}_3 \cdot (\ln Z_{h,t} - \overline{\ln Z_t})^2]. \qquad [10]$$

Here $\hat{a}_1$, $\hat{a}_2$, and $\hat{a}_3$ are econometric estimates of cost function parameters.

A.4 Capital Cost

The benchmarking of capital cost management was noted above to require an estimate of the cost and a means of decomposing it into a price and a quantity. Formally, we must suppose that the cost of each class of utility plant *j* in a given year *t* ($CK_{j,t}$) is the product of a capital service price index ($WKS_{j,t}$) and an index of the quantity of capital on hand at the end of the prior year ($XK_{j,t-1}$)[19].

$$CK_{j,t} = WKS_{j,t} \cdot XK_{j,t-1} \qquad [11]$$

Alternative approaches to capital cost measurement are commonly used in benchmarking. These usually involve replacement cost valuations and standardized treatments of depreciation that are not of straight line character. We examine here the geometric decay approach to capital cost measurement. This approach is widely used in government and scholarly capital cost research.[20]

The geometric decay formula for capital cost is

$$\begin{aligned} CK_{j,t} &= d \cdot VKA_{j,t} + r_t \cdot VKA_{j,t-1} - [(WKA_{j,t} / WKA_{j,t-1}) \cdot VKA_{j,t-1} - VKA_{j,t-1}] \\ &= d \cdot WKA_{j,t} \cdot XK_{j,t-1} = r_t \cdot WKA_{j,t-1} \cdot XK_{j,t-1} \\ &\quad - [(WKA_{j,t} \cdot XK_{j,t-1} - WKA_{j,t-1} \cdot XK_{j,t-1}) \\ &= [d \cdot WKA_{j,t} + r_t \cdot WKA_{j,t-1} - (WKA_{j,t} - WKA_{j,t-1})] \cdot XK_{j,t-1} \end{aligned} \qquad [12]$$

The first term in this expression represents the cost of depreciation. This is the product of the value of plant ($VKA_{j,t}$) and the economic rate of depreciation (*d*). The

[19] It could be argued that capital cost in year t depends more on the amount of capital on hand at the *end* of year t than the amount on hand at the *beginning*. In this discussion, we use the treatment traditionally used in the capital cost literature.

[20] See Hall and Jorgensen (1967) , "Tax Policy and Investment Behavior," American Economic Review, 57 pages 391-410 for a seminal discussion of the geometric decay approach to capital cost measurement.

depreciation rate is assumed to be constant over time and between companies.[21] The value of plant is the product of a capital asset price index ($WKA_{j,t}$) and a capital quantity index ($XK_{j,t}$, as noted above).

The second term in the geometric decay formula corresponds to the opportunity cost of capital. Here r_t, is the opportunity cost of plant ownership per dollar of plant value. This term is sometimes called the cost of funds. It depends on bond yields and the return on equity.[22] The third term in the geometric decay formula for capital cost represents capital gains.

The first step in the calculation of the capital quantity index is to estimate the net *current* value of plant in a benchmark year. This is achieved by adjusting the reported net plant *book* value for the asset price inflation that occurred between the years of investment and the benchmark year. Construction cost indexes are commonly used to measure the inflation in asset prices.[23]

How is the value of the capital quantity index for in subsequent years computed? Consider first that the value of plant in year t is given by the formula

$$\begin{aligned} VK_{j,t} &= (1-d)\cdot(WKA_{j,t}/WKA_{j,t-1})\cdot VK_{j,t-1} + VKI_{j,t} \\ &= (1-d)\cdot(WKA_{j,t}\cdot XK_{j,t-1}) + (WKA_{j,t}\cdot XKI_{j,t}) \end{aligned} \qquad [13]$$

where $VKI_{j,t}$ is capital expenditures and $XKI_{j,t}$ is the *amount* of capital investment. Dividing through by $WKA_{j,t}$ it follows that

$$XK_{j,t} = (1-d)\cdot XK_{j,t-1} + \frac{VI_{j,t}}{WKA_{j,t}}. \qquad [14]$$

This is a perpetual inventory equation. Here, the coefficient *d* is the same constant rate of economic depreciation that is used in the service price formula. VI_t is the

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[21] In our U.S. research we calculate this rate as a weighted average of the depreciation rates for the structures and equipment used in the applicable industry. The depreciation rate for each structure and equipment category is derived from data reported by the Bureau of Economic Analysis of the U.S. Department of Commerce.
[22] As a proxy for this we often calculate the user cost of capital for the U.S. economy using data in the National Income and Product Accounts (NIPA).[22] This variable reflects returns on equity as well as bond yields. The NIPA accounts are published by the BEA in its *Survey of Current Business* series.
[23] The construction cost indexes that PEG uses in U.S. cost research are developed using two data sources. R.S. Means data are used to consider regional differences in construction cost *levels*. Regional Handy-Whitman indexes of utility construction costs are used to calculate trends in construction costs over time. The R.S. Means data are available for Canada. Stats Canada maintains an index of trends in Canadian construction costs.

value of gross additions to utility plant. Notice that a capital quantity index thus calculated is, essentially, an index of the *real* value of utility plant.

A.5 Index-Based Benchmarking

Output Quantity Indexes

Here is an example of a formula for a multi-category output quantity index:

$$\ln Y^{NDX}{}_{h,t} = SUM_i SE_i \ln(Y_{h,i,t} / \overline{Y_{i,t}}). \qquad [15]$$

Here, $Y_{h,i,t}$ is the quantity of output dimension i for the subject utility. $\overline{Y_{i,t}}$ is the sample mean value of the same variable. Each SE_i is the cost elasticity weight for output measure i. These weights would, ideally, come from a *short run* (opex) cost function.

Input Quantity Indexes

Here is an example of a formula for a multi-category *input* quantity index:

$$\begin{aligned} &\ln X^{NDX}{}_{h,t} = SUM_j weight_j \ln(X_{h,j,t} / \overline{X_{j,t}}) \\ &SUM_j weight_j = 1. \end{aligned} \qquad [16]$$

Here, $X_{h,j,t}$ is the amount of input j used by company h and $\overline{X_{j,t}}$ is the mean value of the same variable for the sample. The weights are calculated from cost shares. We might, for example, take an average of the cost shares for the individual utility and the sample.

Unit Cost Indexes

The following formula is an example of a unit cost index that features a multi-category output quantity index.

$$\begin{aligned} &\ln Unit\ Cost_{h,t} = \ln(C^{NDX}{}_{h,t} / Y^{NDX}{}_{h,t}) = \\ &\ln(C_{h,t} / \overline{C_{h,t}}) - SUM_i SE_i \ln(Y_{h,i,t} / \overline{Y_{i,t}}). \end{aligned} \qquad [17]$$

MFP Indexes

The following is an example of formula for an MFP index with a multiple-category output quantity index.

$$\ln MFP_{h,t} = \ln(Y^{NDX}{}_{h,t} / X^{NDX}{}_{h,t}) =$$
$$SUM_i SE_i \ln(Y_{h,i,t} / \overline{Y_{i,t}}) - SUM_j \cdot 0.5 \cdot (SC_{h,j,t} + \overline{SC_{j,t}}) \ln(X_{h,j,t} / \overline{X_{j,t}}). \qquad [18]$$

Index Forms

Alternative forms are available for price and quantity indexes, just as they are for econometric cost models. The most widely used forms are the Las Peyres, Paasche, Tornqvist, and Fisher Ideal. A sizable literature has developed that compares their relative advantages.