K11.3

ONTARIO POWER GENERATION

CROSS-EXAMINATION MATERIALS

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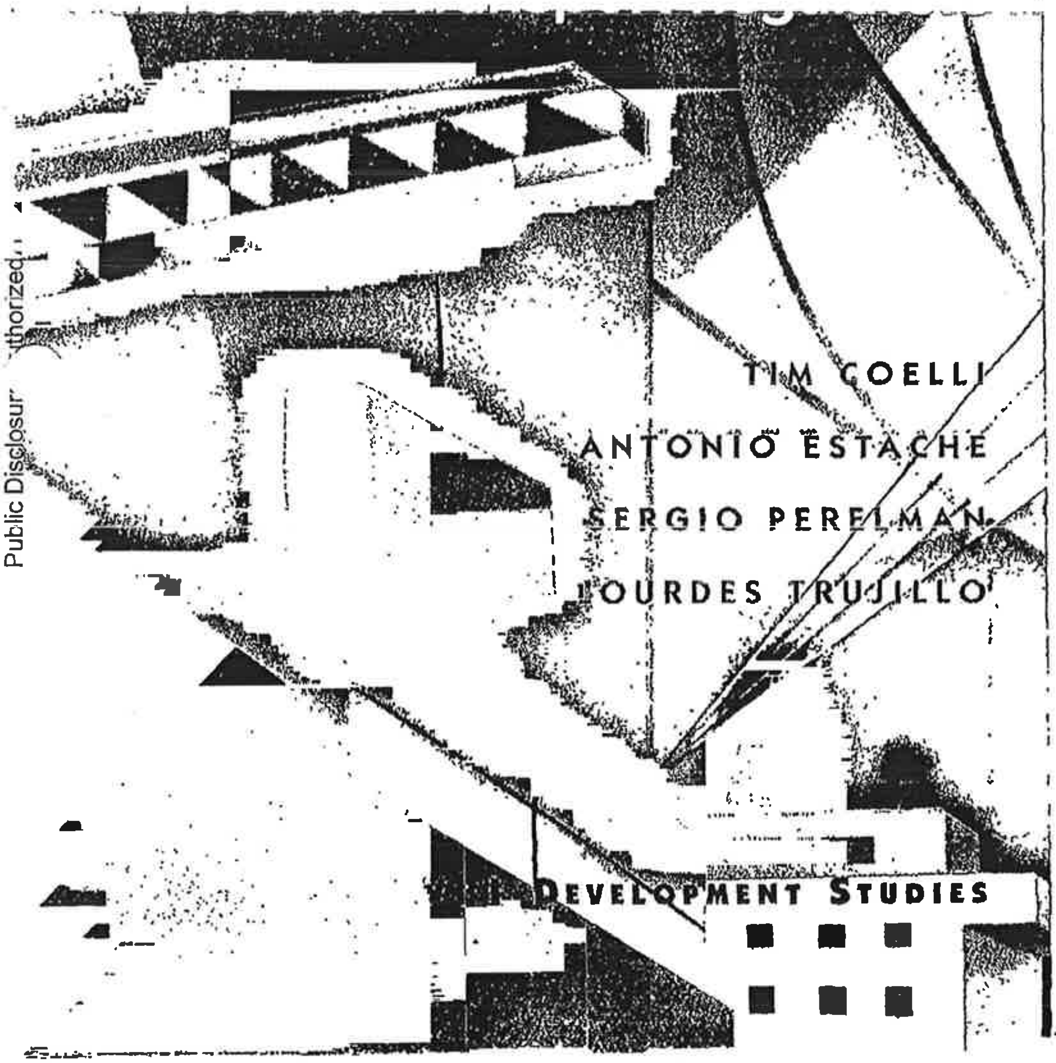

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DEVELOPMENT STUDIES

WBI Development Studies

A Primer on Efficiency Measurement for Utilities and Transport Regulators

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Antonio Estache
Sergio Perelman
Lourdes Trujillo

This primer is supplemented by a database and computer software
that allows the reader to practice the example described in chapter 4.
Visit http://www.worldbank.org/wbi/regulation/pubs/efficiencybook.html.

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Appendix: Capital Measurement

Measuring the quantity, price, and cost of capital is challenging, because capital is a durable input. Unlike other inputs such as labor and fuel, which are generally purchased and consumed within a particular accounting period, say a year, capital is purchased during one period and then supplies services over many periods. Consider the example of a telecommunications company that has purchased a piece of switching equipment that has an expected life of 20 years. The equipment is purchased and installed in year 1 and continues to supply services for another 19 years. So the question we face in our attempt to measure the productivity and efficiency of this firm is: What is the appropriate measure of the quantity and price (and hence cost) of capital in each of these 20 years? We will begin with a discussion that assumes that we have all information available to us. Following this we will discuss the more usual situation where we have limited information.

Capital Quantity

The quantity of capital should reflect the potential service flow that can be derived from the capital equipment in each year. Expecting the potential service flow to be quite similar in each of the 20 years is reasonable, though more down time could be required in the latter years of the asset's life as more maintenance is required. Hence the potential service flow in year 20 could be 5 or 10 percent below that in year 1 (an engineer could provide advice on this matter). In any case, it is often reasonable to assume that the potential service flow will be quite similar from one year to the next.[1] For this reason accountants have often used the method of straight-line depreciation to distribute the purchase cost of an asset over its service life. Thus a piece of equipment that is purchased for US$1,000, which has an expected life of 20 years and an expected scrap value of zero, could be depreciated in the accounts by US$50 per year for the 20-year period.

Thus the depreciation expenses reported in a firm's accounts may provide a good proxy for the quantity of capital each firm uses each year. However, this measure might be problematic because

- Price inflation will make the quantities (that is, the depreciation cost) of new capital items appear larger than identical capital items purchased in previous years.
- Different firms could assume different asset lives or use different depreciation patterns, such as declining balance, or use accelerated depreciation to minimize tax payments.

These problems can be particularly large when dealing with firm-level data in infrastructure industries, where capital investment patterns can be extremely lumpy and where these patterns differ substantially between firms. This factor results in biases in the relative estimates of capital quantity for a particular firm through time, and also produces biased estimates across a group of firms at one point in time.

We can overcome these problems if we have a full history of investment expenditures for each firm and a good index or indexes of price inflation for capital inputs over this period. We can then convert all past nominal investments into constant price values and then apply the same depreciation rules to the constant price undepreciated capital stocks of each firm to obtain good comparable measures of capital quantities.

We could perform these calculations at various levels of aggregation depending on the amount of data and the amount of time available. For example, we could divide capital expenditure into two categories, buildings and fixed structures and machinery and equipment, and then apply different asset lives, and thus different depreciation rates to each category, and so on. If the amount of data (or time) is limited, we can apply an average depreciation schedule to the aggregate capital measures; however, we

1 Note that when we use physical proxies as our capital measures, such as network length and transformer capacity, we are also implicitly assuming that the service flow of the asset is not affected by its age.

Attachment M2-11.1-OPG 2A

1. Introduction

Considerable work has been required for PEG to estimate hydroelectric generation productivity trends using a one hoss shay ("OHS") methodology. The work, which involved development of a new capital treatment, additional data collection, and mathematical analysis, cannot be considered just a simple modification of the PEG work described in Exhibit M2, but is rather a new study. We provide here a thorough discussion of the methodology, data, and calculations.

The first part of our discussion will review the traditional monetary approach to capital quantity measurement and then explain how this methodology is implemented in multifactor productivity ("MFP") research using the geometric decay ("GD") and OHS assumptions. We then discuss our empirical work to implement the OHS method. We conclude with a critique of the OHS method that reflects lessons learned.

2. The Monetary Approach to Capital Quantity Measurement

The monetary approach to capital quantity measurement decomposes capital cost ("*CK*") into a consistent capital quantity index ("*XK*") and capital service price index ("*WKS*") such that

$$CK = WKS \cdot XK^{1} \quad [1]$$

[1] The *growth rate* of capital cost is thus the sum of the growth rates of the capital price and quantity indexes.

The cost of capital includes depreciation expenses, a return on investment, and certain taxes. If the price (unit value) of the asset changes over time this cost may also be net of any capital gains or losses.

In MFP research it is customary to assume that a capital good provides a stream of valuable services over a period of time that is called the service life of the asset. The capital service price index measures the trend in price of the stream of services provided by one unit of capital. The product of the capital service price index and the capital quantity index is the annual cost of using the flow of services.

A capital service price index is sometimes called a *rental* price index since, in markets for rentals of assets (e.g., automobiles and apartments), there are observable prices per unit of service from assets. Suppose, for example, that landlords own 1,000 identical houses and that these assets are each valued at a price established in the real estate market. They rent out each house at a price per month of use that is set in the market for housing rentals. The monthly cost to tenants of using the houses is the sum of their monthly rental payments. The trend in the user cost of housing rentals is the sum of the trends in rental rates and the number of houses.

Well-developed markets do not exist for the rental of most assets that utilities own. However, capital service prices can be imputed for these assets that permit an imputation of the user cost of capital. These prices are founded on the assumption that the ("stock") value of a capital asset is the expected discounted value of the stream of services that the asset provides. There is then an equation linking the price of a unit of a capital asset ("WKA") to future prices of capital services. Manipulation of this equation makes it possible to express the capital service price in a given year as a function of capital asset prices and the rate of return on capital. This function also depends on the assumed pattern of decay in the flow of services from assets.

Better Regulation

Explanatory Statement

Expenditure Forecast Assessment Guideline

November 2013

AUSTRALIAN
ENERGY
REGULATOR

- legal and accounting PPI—3.0 per cent
- market research and statistical services PPI—1.0 per cent.

We note the weights use opex shares Pacific Economics Group (PEG) adopted in 2004, which were based on analysis of Victorian electricity DNSP regulatory accounts data.[556]

We consider it appropriate to use these existing weights as a starting point until analysis on DNSP and TNSP opex weights that use current data, is available. Economic Insights recommended WPI as the appropriate opex price index (not the AWOTE) and we agree. It has some theoretical advantages over the AWOTE. We used WPI in previous decisions, given concerns about the volatility of the AWOTE at the time.[557] However, further these purposes, the difference in net regulatory effect is minimal if either measure is applied consistently in economic benchmarking.[558] We consider it appropriate to use the AWOTE for sensitivity testing.

B.3.2 Capital inputs

AER position

We support Economic Insights' recommendation to use physical capital measures to proxy the annual capital service flow.[559] That is, before allocating the cost of assets over multiple years, it is necessary to estimate the quantity of capital inputs used in the production process each year. This is also known as the flow of capital services.[560]

The quantity of capital inputs employed each year in the production process will depend on the asset's physical depreciation profile. We consider capital inputs follow a one hoss shay depreciation profile, where the flow of capital services remains constant over time.

We agree with Economic Insight's recommendation that other measures of capital inputs, such as a RAB straight-line depreciation proxy, or depreciated RAB proxy, warrant further investigation.[561]

Reasons for position

We propose to use physical capital measures to approximate the capital service flow for economic benchmarking. We did not receive further submissions on the use of capital flow as a capital input. However, as discussed previously, NERA noted the 'lumpiness' of TNSP's capital expenditure profile may present difficulties in economic benchmarking TNSPs. Although, NERA further noted the extent to which this lumpiness of capex may pose a difficulty for benchmarking analysis depends on exactly what is being benchmarked.[562]

As discussed previously, economic benchmarking does not involve a process where capex is directly benchmarked. Rather, economic benchmarking uses the annual user cost of capital (AUC) as the associated annual input cost of capital, and the total stock of capital to calculate the flow of capital services into an NSP's production process. We noted in the explanatory statement to the Draft Guideline that capex is not an appropriate measure of capital inputs. Capex represents expenditure on new capital assets and, except under rare circumstances, is not equal to the annual use of capital

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556 Pacific Economics Group (PEG) (2004), *TFP Research for Victoria's Power Distribution Industry, Report prepared for the Essential Services Commission*, Madison.
557 AER, *Draft decision: Powerlink transmission determination 2012–13 to 2016–17*, November 2012, pp. 57–59.
558 Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 85.
559 Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 85.
560 Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 47.
561 Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 63.
562 NERA, *Holistic economic benchmarking – A report prepared for Grid Australia*, 20 September 2013, p. 11.

assets.[563] Further, as noted by NERA, because our approach incorporates the existing asset base and new capex, and because we do not propose to benchmark capex, the issue of NSPs' lumpy investment provide is reduced.

In relation to the possible use of alternative capital input methodologies, we consider RAB depreciation may be a useful starting point for measuring the annual capital input.[564] Economic Insights considered RAB depreciation could produce a series similar to a one hoss shay proxy in principle, but that it also identified the issues raised in submissions and recommended further investigating using RAB depreciation.[565]

We consider the RAB straight line depreciation proxy may provide a similar result to the one hoss shay physical capital measure in principle. Further, the depreciated RAB proxy is relatively simple to calculate. However, in practice these two methods may not produce results that are consistent with the use of physical capital measures. We agree with Economic Insight's recommendation that these two proxies warrant further investigation.

B.4 Operating environment factors

B.4.1 AER position

We have renamed environmental variables to operating environment factors. We consider this new name better reflects the differences between the NSPs exogenous operating conditions. Operating environment factors outside of a NSP's control can affect its ability to convert inputs into outputs. There is overlap between inputs, outputs and environmental variables used in previous economic benchmarking studies. Similar to outputs, there is a diversity of views in the economic literature on the choice of operating environment factors.

The operating environment factors discussed in this section have been identified as possible factors that may have a material effect on NSP efficiency. However, we do not currently have data on these environmental variables and our decision to incorporate these factors will depend on their materiality and statistical relationship once we have data.

Table B.7 shows a shortlist of the operating environment factors we will be collecting data for in the economic benchmarking RIN and from other sources such as the Bureau of Meteorology. More information on the format in which we will be collecting these variables is in the draft economic benchmarking RIN templates.[566]

Table B.7 Operating environment factors shortlist

DNSP operating environment factors	TNSP operating environment factors
Weather factors	**Weather factors**
Extreme heat days	Extreme heat days
Extreme cold days	Extreme cold days
Extreme wind days	Extreme wind days

563 The measures of capital are affected indirectly by capex. That is, capex, along with depreciation, do affect asset values from year to year. However, the new assets generally make a small contribution to measures of overall capital services flow. Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 50.

564 SP AusNet, *Expenditure Forecast Assessment Guidelines– Issues Paper,* 15 March 2013, p. 21.

565 Economic Insights, *Economic benchmarking of electricity network service providers*, 25 June 2013, p. 63.

566 The economic benchmarking data templates are available at: http://www.aer.gov.au/node/21836

	Average wind speed
Terrain factors	**Terrain factors**
Bushfire risk	Bushfire risk
Rural proportion	Vegetation encroachment: growth
Vegetation encroachment: growth	Vegetation encroachment: topography
Vegetation encroachment: topography	Vegetation encroachment: bushfire risk
Vegetation encroachment: bushfire risk	Standard vehicle access
Standard vehicle access	Altitude
Network characteristics	**Network characteristics**
Line length	Line length
Density factors	Variability of dispatch
Customer density	Concentrated load distance
Energy density	
Demand density	

This shortlist is not an exhaustive list of all factors that may have an exogenous effect on NSPs costs and additional operating environment factors may be added as more robust data becomes available.

B.4.2 Reasons for AER position

Our operating environment factors short list reflects the operating environment factors we consider to have a material impact on NSPs costs and can potentially be collected on a consistent basis across all DNSPs and TNSPs.

PIAC noted category analysis goes some way to addressing the different exogenous circumstances facing each NSP. Aggregating category benchmarking may enable higher level comparisons of performance while controlling for the more obvious expenditure drivers such as size and load density.[567]

We consider utilising multiple assessment techniques to determine the effect of operating environment factors both qualitatively and quantitatively.

As discussed previously, NERA submitted that a weakness of economic benchmarking is that it overlooks operating environment factors that are business specific and 'inefficiency' may simply represent environment or other variables not taken into account. NERA submitted that the AER must recognise the limitations of conclusions drawn from economic benchmarking of firms operating in diverse circumstances.[568]

We consider it is important when interpreting our economic benchmarking results to recognise the data that has been used to model efficiency. Our selection criteria require the operating environment factors to be material and to also be the primary driver of costs. We note although not every possible exogenous factor has been included in our shortlist, some factors may have a similar effect to factors

567 Public Interest Advocacy Centre, *A firm basis: submission to the AER's Draft expenditure forecast assessment guideline*, 20 September 2013, p. 16.

568 NERA, *Holistic economic benchmarking – A report prepared for Grid Australia*, 20 September 2013, p. 52.

Submission to Australian Energy Market Commission: Design Discussion Paper

Pacific Economics Group, LLC

Economic and Litigation Consulting

Submission to Australian Energy Market Commission: Design Discussion Paper

October 2009

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1. INTRODUCTION

The Australian Energy Market Commission (AEMC) is undertaking a review into the use of total factor productivity for the determination of prices and revenues. This review is examining whether a "TFP-based approach" to network price regulation should be added as an option to Australia's current framework for regulating prices of energy network services. To provide further clarity for this review, the AEMC recently released a Design Discussion Paper that puts forward a possible TFP-based regulatory model and methodology.

This submission presents my personal views on the AEMC's Discussion Paper. These views do not necessarily represent those of either of the two firms where I currently serve as a Senior Advisor (Pacific Economics Group (PEG) or Navigant Consulting). They also do not necessarily represent the views of the Essential Services Commission of Victoria, which I have advised for the last six years on a variety of regulatory topics. However, they do reflect my work on this topic for more than 12 years in Australia, as well as my experience advising on TFP and incentive regulation in a wide variety of diverse environments in North America, South America, the Caribbean, Europe, and Asia.

In general, I believe the Discussion Paper represents a significant step forward in crafting a practical and appropriate TFP-based regulatory option. The model advanced for discussion generally balances the objectives of creating a stable regulatory framework and allowing for flexibility in how TFP-based regulation may be adapted and applied to the circumstances of specific distributors. In balancing these aims, the model presented in the Discussion Paper has likely increased the incremental benefits from a TFP-based option without substantially increasing the incremental development and administrative costs.

The main outstanding issues concern the methods to be used for estimating TFP itself. In my opinion, the discussion surrounding this issue has too often veered into academic matters and has lost sight of the main practical objective, which is using TFP-based regulatory methods to set appropriate changes in *utility prices*. The algebra underpinning the rationale for TFP-based regulation establishes a direct link between changes in utility prices and changes in the industry's unit cost of providing utility services. The TFP specification should satisfy this fundamental relationship, and I believe that if we keep this criterion in mind the debates surrounding TFP measurement can be resolved and an appropriate TFP specification thereby identified.

I have addressed TFP measurement issues at some length in several submissions presented in the ongoing update of New Zealand's TFP-based regulatory approach. Rather than reiterate those detailed discussions here, I have included these analyses as appendices to this submission. One of these appendices attaches the full text of my most recent submission, which addresses Economic Insights' (EI's) claim that my analysis of TFP-based regulation assumes that the utility industry is characterized by competitive market conditions. This claim has been echoed during the AEMC's review, and it is entirely without foundation. Moreover, this error is so profound and misleading that, in the interest of establishing a full, accurate and transparent record in this proceeding, I believe it should be retracted and rectified in the AEMC's subsequent reports.

Following this introduction, the next section discusses the appropriate TFP specification. Section Three addresses the various design issues that the Discussion Paper puts forward for a TFP-based regulatory option. Section Four addresses a number of miscellaneous issues in the Discussion Paper, and Section Five presents brief concluding remarks.

industry input prices (*i.e.* the growth rate in industry TFP is subtracted from the growth rate in industry input prices), it leads to a rate of change that is equal to the observed change in the industry's unit cost of providing regulated services. This is the most important criterion that must be satisfied when identifying the correct TFP specification, because if it is not then the underlying rationale for TFP-based regulation is violated. Moreover, this criterion is amenable to direct empirical tests: rival TFP specifications can be examined to see which is most consistent generating the observed change in the industry's unit cost of providing regulated services. Clearly, for this to be a practical regulatory approach, this unit cost of service must also be one that can be computed from, and is consistent with, the industry's actual observed data.

The Correct TFP Specification

The logic underlying TFP-based regulation also has direct implications for how inputs and outputs should be measured to ensure that the TFP specification leads to changes that are consistent with the rate of change in the industry's unit costs. This logic has been described in the ESC's submissions during this review, and it is also addressed in Appendices One (output choices) and Two (capital measurement) of this report. Essentially, the basic algebra shows that outputs must be measured by the billing determinants (weighted by their revenue shares), and both operating and capital inputs must be measured using monetary values (weighted by their cost shares). No other TFP specification is consistent with the underlying indexing logic, or will ensure that the fundamental criterion for TFP-based regulation (discussed above) is satisfied.

I should note that EI has recently said the indexing logic presented in my work assumes that regulated industries are characterized by competitive market conditions. This claim has been echoed in the AEMC's Discussion Paper (*e.g.* on p. 26 and p. 60), but it is entirely incorrect. I have addressed EI's claims in detail in my most recent submission in New Zealand, and the full text of this document is attached as Appendix Three.[3]

[3] One clarification of this analysis is in order, however. On page 20 of my last New Zealand submission (the next to last page in Section Three; the page ordering in this document is different), I refer to "the derivative of the cost with respect to an input is the marginal cost that EI refers to above;" I should have been more clear that I was referring to the derivative of the opex cost function EI specified in its

APPENDIX TWO: MEASUREMENT OF CAPITAL

*(Note: the following discussion originally appeared as Appendix Two in Kaufmann, L and D. Hovde., **X Factor Recommendations for New Zealand Electricity Distribution Price Controls**, July 2009, pp. 43-51)*

PHYSICAL VERSUS MONETARY CAPITAL MEASURES AND ALTERNATIVE DEPRECIATION ASSUMPTIONS

In the past several years, there has been an extensive debate in Australia and New Zealand about whether physical or monetary values of capital assets should be used to measure capital input quantities in TFP studies. These options have also sometimes been referred to as the direct (*i.e.* physical) and indirect (*i.e.* monetary) approaches to capital measurement. This appendix will consider the issue of using physical versus monetary measures for capital inputs. With extremely rare exceptions, PEG believes that only monetary measures of capital stocks should be used to measure capital in energy utility TFP studies. This view is overwhelmingly supported by economic theory, empirical evidence and regulatory precedent.

One important factor supporting the use of monetary capital values is the indexing logic which demonstrates the role that industry total factor productivity (TFP) trends can play in adjusting utility rates. This logic shows that only monetary capital values are internally consistent with the TFP trend measures that should be used in rate adjustment mechanisms. Recall that the indexing logic examines long-run changes in revenues and costs for an industry. In the long run, the trend in revenue (R) for an industry equals the trend in its cost (C).

$$Trend\ R = Trend\ C \tag{1}$$

The trend in the revenue of any industry will be equal to the sum of trends in revenue-weighted output price indexes (P) and revenue-weighted output quantity indexes (Y).

$$Trend\ R = Trend\ P + Trend\ Y \tag{2}$$

The growth rate in the cost incurred by an industry is the sum of the trends in a cost share-weighted input price index (W) and a cost-share weighted input quantity index (X).

$$Trend\ C = Trend\ W + Trend\ X \tag{3}$$

Substituting (2) and (3) into equation (1) and rearranging, we find

$$\begin{aligned} Trend\ P &= (Trend\ W + Trend\ X) - Trend\ Y \\ &= Trend\ W - (Trend\ Y - Trend\ X) \\ &= Trend\ W - Trend\ TFP \end{aligned} \tag{4}$$

It can be seen that the trend in (revenue-weighted) prices depends on the difference between the trends in two indexes. The first is a *cost-share weighted* input price index. The second is a total factor productivity (TFP) index. The trend in output quantities used in the TFP index is calculated using revenue-share weights; the trend in input quantities used in the TFP index is calculated using cost-share weights.

In terms of the choices for capital inputs, the critical relationship in this logic is equation (3). This equation shows that there is a direct link between the input quantity measure used in TFP calculations and the costs of the industry. In other words, the trend change in the industry's input quantity (which is used, in turn, to compute industry TFP trends) should be associated with trend changes in industry cost. This relationship naturally applies to capital inputs, which account for the largest share of energy network inputs.

Clearly, the total cost of the industry is measured in monetary terms, and internal consistency requires this value to be decomposed into two component indices (for input prices and input quantities) that are measured on the same, monetary basis. This is almost invariably the case for opex inputs, which are measured using the monetary values for operating expenditures. These monetary values are "deflated" using an opex input price index, which functionally divides the monetary value of opex changes into a price change component (reflected in the change in the overall input price index, W) and a quantity change component (reflected in the change in the overall input quantity index, *X*). Capital input quantities will be logically consistent with the total cost and opex input quantity measures only if these indices are also calculated using monetary capital values.[7]

The link between monetary capital values and TFP trends is also consistent with how utility prices are set in practice. When prices under a CPI-X regulation plan are updated using measures of industry input price and TFP trends, prices at the outset of the plan are typically set to recover the company's cost of service in a base year. These initial year costs include the costs associated with capital assets. When a utility sets its rates to recover the depreciation and carrying costs of these capital goods, it does so with reference to the aggregated monetary values of these disparate assets, net of their depreciation. It follows that if monetary costs – including the monetary costs of physical capital assets - are used to set rates at the outset of a plan but a "physical method" for measuring capital is used to set the X factor, the X factor to *adjust* distribution rates will not be consistent with how those rates were originally set. This internal inconsistency between setting initial rates and adjusting rates over time can only reduce the transparency of the rate adjustment mechanism and perhaps exacerbate rate volatility when prices are updated, thereby undermining the predictability and effectiveness of the incentive regulation regime.

It should also be noted that the use of physical capital measures in TFP studies embody certain assumptions about depreciation. A necessary, but not sufficient, condition for using physical capital to measure the capital stock is for capital to obey what is known as "one-hoss shay" depreciation. The defining characteristic of one-hoss shay depreciation is that the asset undergoes *no* physical decay from the time it is installed until the day it is replaced. The classic example of a one-hoss shay "asset" is a light bulb.

The link between one hoss shay depreciation and physical capital can perhaps be clarified by considering that TFP growth is designed to measure the flow of services provided by aggregate inputs. The services provided by a given capital good depend on how efficiently that asset is operating compared with its potential. Economists

[7] Indexes that obey this property are sometimes said to satisfy the "product test"; for example, see Waters, W.G. and J. Street (1998), "Monitoring the Performance of Government Trading Enterprises," *The Australian Economic Review*, Vol. 31, no. 4, p. 368.

sometimes term this relationship between actual and potential services as the "efficiency units" associated with a given capital good. Whenever there is any physical asset decay, then the efficiency units of older capital must be less than the efficiency units of the newer capital. If this is the case, then old and new capital goods cannot simply be added together and used to measure capital input because there is effectively less input quantity being provided by the older capital goods. Different physical values for capital goods (such as km of distribution line installed in different years) can therefore be added together and used as an overall capital measure only when there is no physical decay in assets *i.e.* when there is one-hoss shay depreciation. When this is not the case, then the capital inputs installed in different years must also be adjusted to take account of capital decay that has taken place since the assets were put in place.

PEG does not believe that a one-hoss shay depreciation pattern (*i.e.* zero physical decay in every year an asset is in place) is consistent with day-to-day experience in energy network industries. For example, scores of utilities have implemented "reliability centered maintenance" programs which are designed to optimize system performance and extend asset life. Distribution maintenance involves many concrete decisions about inspection cycles, washing insulators, whether and when to treat or "wrap" wood poles, vegetation management, etc. Even though distribution assets tend to be long-lived, the fact that they involve extensive maintenance programs is a sure sign that there is some physical decay over time. It would be imprudent and unprofitable for utilities to devote resources to asset maintenance unless doing so increased the services effectively provided by these capital inputs. Such maintenance programs would also not be consistent with a one-hoss shay depreciation pattern, where the assets must be providing a constant stream of services *before* maintenance programs are undertaken.[8]

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[8] It has been argued that the presence of maintenance expenditures can be consistent with one-hoss shay depreciation, since agricultural land sometimes includes expenditures to maintain the productivity of given lands and yet land typically is assumed not to depreciate in TFP studies. However, there is an important distinction to be made between "no depreciation" and one-hoss shay depreciation. The difference is that, with very rare exceptions, land is not physically replaced at all, so it is appropriate to assume that there is no depreciation since the concept is inherently designed to measure the extent to which assets are "used up" over time as they are utilized in production. Other than land, all assets will inevitably be completely used up at some point and hence must be replaced (assuming ongoing operation of the enterprise and that the asset has not become technologically obsolete). This disparity between land and other assets implies that the zero depreciation for land assets is not equivalent to one-hoss shay depreciation.

A corollary of the "no physical decay" condition is that one hoss shay assets also provide unmistakable replacement signals. One-hoss shay capital goods work perfectly until the day they break down, at which point they never work again and must be replaced. This also does not reflect the reality of most energy network assets. Managers have a degree of discretion about when to replace assets and, to a lesser extent, about replacing current labor-based operations with capital equipment (*e.g.* in service restoration). Replacement decisions are, in fact, intertwined with operational and maintenance decisions. The complexity and inter-relatedness of these judgments is not consistent with the transparent simplicity of deciding when to replace a light bulb or other one-hoss shay assets.

The economics literature also generally supports the notion that energy network assets are not characterized by one-hoss shay depreciation. Indeed, this literature has found exceedingly few assets with one hoss shay depreciation profiles in any industry. One statement of this view comes from an OECD Manual titled *Measuring Capital: Measurement of Capital Stocks, Consumption of Fixed Capital, and Capital Services:*

> "There are probably rather few assets that maintain constant efficiency throughout their working lives. Light bulbs are sometimes cited as potential one-hoss shays, but light-bulbs are too short-lived to be classified as capital goods. More serious contenders might be bridges or dams. With a constant level of maintenance these structures may continue to provide constant rentals for very long periods. In general, however, few examples of the one-hoss shay have been identified in the real world."[9]

The literature also finds that when observers ignore the role of maintenance expenditures, they often incorrectly conclude that assets exhibit one hoss shay depreciation. This has been noted in the *Dictionary of Usage for Capital Measurement Issues*, released in conjunction with the Second Meeting of the Canberra Group on Capital Stock Statistics:

> "The concept of decay is a crucial one in capital measurement. Some additional remarks about input and output decay may clarify the concepts. The division between output decay and input decay is economically, not technologically, determined, because owners can often offset output decay by increased maintenance. However, increased maintenance as a capital good

[9] OECD Manual. (2001). Measuring Capital – Measurement of Capital Stocks, Consumption of Fixed Capital and Capital Services.

ages implies input decay. Accordingly, when increased maintenance does compensate for output decay, this does not create a one hoss shay asset, because a one hoss shay asset is by definition one with zero decay. There seems to be some confusion on this point in the literature: A good deal of the anecdotal evidence that has been cited in favor of the plausibility of the one hoss shay model has ignored input decay."[10]

Arguments in favor of one hoss shay depreciation based on "casual experience" or "intuitive appeal" also run contrary to rigorous empirical depreciation studies. For example, when discussing alternative depreciation patterns, Charles Hulten (a depreciation expert) writes that observers often believe "...the one hoss shay pattern commands the most intuitive appeal. Casual experience with commonly used assets suggests that most assets have pretty much the same level of efficiency regardless of their age – a one year old chair does the same job as a 20 year old chair, and so on."[11] However, this author's own academic work shows that this "casual experience" conflicts with more scientific investigations of depreciation. Hulten and Wykoff examined the prices that were actually paid in secondary markets for used capital goods.[12] They found that these prices were most consistent with geometric and not one-hoss shay depreciation patterns. This work has been very influential and is used directly by a number of researchers (including the US Bureau of Economic analysis) to value capital stocks. Surveying the intuitive and empirical arguments, Hulten writes:

> "Taken together, these intuitive arguments (in favor of one hoss shay) above suggest that this is a case in which the econometric evidence leads to the wrong result. However, it may also be true that the intuition, not the econometrics, is faulty. Intuition tends to be based on personal experience of individual cases."[13]

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[10] Triplett, Jack. (1998). *A Dictionary of Usage for Capital Measurement Issues*, presented at the Second Meeting of the Canberra Group on Capital Stock Statistics (OECD).

[11] C. Hulten (1990), "The Measurement of Capital" in *Fifty Years of Economic Measurement* eds. E.R. Berndt and J. Triplett, Studies in Income and Wealth, vol. 54, the National Bureau of Economic Research, Chicago: The University of Chicago Press, p. 124.

[12] C. Hulten and F. Wykoff (1981), "The Measurement of Economic Depreciation," in *Depreciation, Inflation and the Taxation of Income from Capital* ed. C. Hulten, Washington DC: The Urban Institute Press. 81-125.

[13] Hulten, Charles R & Wykoff, Frank C. (Jan 1996). Issues in the measurement of economic depreciation: Introductory remarks. *Economic Inquiry 34*(1), pp. 10-24.

Furthermore, Hulten notes that proponents of one-hoss shay depreciation ignore what is known as the "portfolio effect," *i.e.* the depreciation profile associated with a group of disparate assets – such as those owned by energy networks– will often differ from the depreciation of any individual asset. He writes:

> "Moreover, what may be true on a case-by-case basis may not be true of an entire population of assets. If so, this has important implications for evaluating econometric results, which typically reflect the average experience of whole populations and not individual units. For instance, it may well be true that every single asset in a group of 1000 assets depreciates as a one-hoss shay, but that the group as a whole experiences near-geometric depreciation. This fallacy of composition arises from the fact that different assets in the group are retired at different dates: some may last only a year or two, others ten to fifteen years. When the experience of the short-lived assets is averaged against the experience of the long-lived assets, and the average cohort experience is graphed, it will look nearly geometric if the 1000 assets have a retirement distribution of the sort used by the Bureau of Economic Analysis (i.e., one of the Winfrey distributions). Thus, the average asset (in the sense of an asset that embodies the experience of 1/1000 each of 1000 assets in the group) is not one hoss shay, but something that is much closer to the geometric pattern. This can easily be verified by performing this experiment using the parameters of the Bureau of Economic Analysis's capital stock program."[14]

Other depreciation experts have also expressed the view that one hoss shay deprecation is not consistent with the empirical literature. One reason, again, is that arguments in favor of one hoss shay depreciation do not consider the implications of maintenance expenditures, which can be used to increase the flow of services that assets provide over their lifetimes. For example, Erwin Diewert has written:

> "The one hoss shay model of efficiency decline, while seemingly a priori attractive, does not seem to work well empirically; i.e. vintage depreciation rates tend to be much more accelerated than the rates implied by the one hoss shay model. We also saw in Section 11 that the simple one hoss shay model does not take into account the implications of rising maintenance and operating costs for an asset as it ages. Thus if maintenance costs are linearly rising over time, a "gross" one hoss shay model gives rise to a linearly declining efficiency model, which of course, is a model that exhibits very

[14] Hulten, Charles R & Wykoff, Frank C. (Jan 1996). Issues in the measurement of economic depreciation: Introductory remarks. *Economic Inquiry 34*(1), pp. 10-24.

accelerated depreciation" (and therefore not consistent with one hoss shay depreciation)[15]

It should also be noted that very few TFP studies used in regulatory applications have used physical capital measures. The only such precedent that PEG is aware of is in the New Zealand electricity thresholds regime. Far more regulatory plans have used monetary capital values as the basis for approved TFP trends. Simple capital measures have also been criticized in other Australian regulatory proceedings. In 1999, Denis Lawrence (then with Tasman Asia Pacific, currently with Economic Insights) made the following comments regarding the capital cost measure used by London Economics in a study done for the Independent Pricing and Regulatory Tribunal:

> "Of more fundamental concern, however, is the attempt to measure capital input simply by the route kilometers of lines and MVA of transformer capacity. The measure of capital inputs should take account not only of quality differences between capital inputs but also capture the amount of resources which have to be expended to construct the capital input. Particularly in the case of lines, simply adding kilometers of lines together is inappropriate. It fails to recognize the inherent differences between central business district, suburban and rural situations...Treating all kilometers of line as being identical is akin to measuring aircraft inputs by the number of miles flown. If one of those kilometers is flown by a Boeing 747 and another is flown by a Cessna, the inappropriateness of the assumption is apparent."[16]

It should also be noted that the issue of appropriate capital measures was the subject of considerable debate in a 2007-2008 update of an incentive regulation plan for power distributors in the Canadian Province of Ontario. PEG was advising the Ontario Energy Board (OEB) in this proceeding, and we estimated an industry TFP trend using

[15] E.W. Diewert, (June 2001), Measuring the Price and Quantity as Capital Services under Alternative Assumptions. Discussion Paper No. 01-24, p. 73. Immediately below these lines, Diewert also writes "the straight line depreciation model, *while not as inconsistent with the data as the one hoss shay model,* also does not generate the pattern of accelerated depreciation that seems to characterize many used asset markets" (emphasis added). Thus of the three main candidates for depreciation profiles, these statements imply that one hoss shay is the least consistent with empirical depreciation studies, straight line depreciation is the second least consistent, and geometric depreciation is most consistent.

[16] Lawrence, Denis. (March 1999). *Report to Energy Australia on London Economics Efficiency and Benchmarking Study on the New South Wales (NSW) Distribution Business.* It should be noted that the London Economics studies included benchmarking and TFP results, but arguments regarding the merits of monetary versus physical capital measures are generally applicable to each type of empirical study. However, because there fewer concerns about the consistency with the underlying indexing logic, PEG

monetary capital values. London Economics (represented by Julia Frayer) developed an alternative TFP measure which used physical capital measures in part. In its September 2008 final decision, the OEB accepted PEG's approach and wrote that "(o)f greatest concern with Ms. Frayer's approach is the (physical) measurement of capital, which is inconsistent with the prior Ontario TFP studies and does not appear to have been adopted in any jurisdiction other than New Zealand."[17] This is one of the few, and perhaps only, instances in which the merits of physical versus monetary capital values was debated extensively and transparently in a regulatory setting.

In sum, PEG agrees that "the measure of capital inputs should...capture the amount of resources which have to be expended to construct the capital input." We believe that this view is supported by the fundamentals of utility ratemaking, the logic underlying productivity-based regulation plans, day-to-day experience in energy network industries, the empirical evidence on observed depreciation patterns, and the overwhelming bulk of regulatory precedents.

believes that physical capital measures are generally less problematic in benchmarking than TFP applications.

[17] Ontario Energy Board, *Supplemental Report of the Board on 3rd Generation Incentive Regulation for Ontario's Electricity Distributors*, September 17, 2008, p. 12.

AUC
Alberta Utilities Commission

Errata to Decision 20414-D01-2016

2018-2022 Performance-Based Regulation Plans for Alberta Electric and Gas Distribution Utilities

February 6, 2017

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distribution system."[146] Dr. Pavlovic expressed his view that "the proper measures of output for a distribution operation are customers, customers served, and peak capacity."[147] In explaining his position at the hearing,[148] Dr. Pavlovic discussed the "Electric Utility Cost Allocation Manual" published by the National Association of Regulatory Utility Commissioners,[149] in support of his position. Reasons for his position, linking customers as an output measure and cost drivers and cost allocations for electric distribution utilities, were not fully explained.

129. The Lowry study uses number of customers as the output measure for a number of reasons, including its applicability with a revenue-per-customer cap. Dr. Lowry also pointed to the use of econometric modelling that shows the number of customers to be a more important driver of the costs of energy distributors than delivery volumes. An additional reason is that the number of customers is much more stable (that is, less variable) than the trend in delivery volumes.[150] The Commission does not find these reasons to be particularly persuasive in terms of attaching higher weight to studies that use the number of customers as the output variable rather than a volumetric measure. First, only gas distribution utilities will be under a revenue cap plan in the next generation PBR plans (electric distribution utilities remain under a price cap) and, in any event, as Dr. Carpenter[151] and Dr. Meitzen pointed out,[152] what is more relevant is the type of index that applies to the U.S. electric distribution firms in the sample, an issue on which no evidence has been adduced. Second, the evidence provided was insufficient to explain why, finding that the number of customers is a more important driver of the costs of energy distributors than delivery volumes, means that the number of customers is a better measure of output than delivery volumes. Finally, while a lack of variability of an output measure appears to have some advantages in terms of ease of numerical calculation and updating, expert evidence was not provided as to why in and of itself, this characteristic is particularly desirable in terms of deciding which output measure is more relevant.

130. In this context, the Commission acknowledges that with the prevalence of both fixed and variable revenue components for distribution utilities, the number of customers is a relevant output measure along with volume, where the relative weights assigned to these two output measures would ideally reflect the proportion of revenues generated through fixed versus variable (volumetric) charges.[153] In the absence of such information for the firms in the U.S. sample, the Commission is not prepared to discount TFP growth studies developed using either volume or number of customers as the output measure simply because of the particular output measure that was chosen, but in future would prefer sensitivity analysis that demonstrates the effect on output growth, and hence TFP growth, of varying the relative weights that are assigned to each of these two output measures.

131. The average annual growth rates associated with the number of customers output measure for 1997-2014 were 0.90 per cent for the Lowry study using the full sample,[154] and 0.86 per cent when Dr. Meitzen redid his analysis using this output measure with the 67 firm Brattle sample

146 Exhibit 20414-X0403, UCA reply evidence of Dr. Pavlovic et al., page 6, Q/A 14.
147 Transcript, Volume 17, page 3569, lines 6-8 (Dr. Pavlovic).
148 Transcript, Volume 17, page 3632, line 1 to page 3632, line 18.
149 UCA reply evidence in Exhibit 20414-X0403, PDF page 8.
150 Exhibit 20414-X0630, PDF pages 40-42.
151 Transcript, Volume 2, page 406, line 11 to page 407, line 3 (Dr. Carpenter).
152 Exhibit 20414-X0256, EDTI-AUC-2016APR15-013(f).
153 Exhibit 20414-X0173, BRATTLE-AUC-2016APR15-009(b); Exhibit 20414-X0256, EDTI-AUC-2016APR15-013(e); Exhibit 20414-X0321, CCA-AUC-2016APR15-009(d).
154 Exhibit 20414-X0468, PDF pages 40, 42.

for 2000-2014.[155] For volume, the average annual growth rates were 0.51 per cent for the Brattle study and 0.50 per cent for the Meitzen study, using the last 15 years and the Brattle sample of firms in both cases.[156] These growth rates are not all directly comparable, however, for the same reasons identified previously when comparing the results of the different assumptions pertaining to inputs; namely, differences in the firms included in the samples, in the method of aggregating across firms and, additionally, in this case, in the data period and data sources used. Using the 53 firms that are common to the Brattle and Lowry studies, growth in the number of customers is 0.88 per cent for 2000-2014.[157] Volume growth for these same firms in this same period is 0.64 per cent using the weighted average approach in the Brattle study, or 0.47 per cent if all firms are weighted equally.[158] Therefore, after controlling for differences between the studies, the difference in output measures, number of customers versus volume, affects annual growth by between 0.24 and 0.41 percentage points for this period, a number that translates directly into TFP growth differences since TFP growth is output growth less input growth.

132. A further issue with the output data concerns the source for the customer count data. Most of these data are taken from FERC Form 1, but the Lowry study combines output data from FERC Form 1 and EIA Form 861, as described previously.[159] Specifically, for a majority of firms, the Lowry study uses Form 1 data until 2000 and then Form 861 data thereafter. However, for some firms the Lowry study uses Form 1 data throughout while in others it uses Form 861 data throughout, even though for almost 35 per cent of the 88 firms the two data series are identical in all years, and for a further 30 per cent there are only a few minor differences between the two series for any particular firm in some years.[160] Some parties viewed this patching of data as problematic,[161] but patching data in this way can avoid obvious transcription errors in the original data. However, here there are anomalies that remain even in the patched data.[162]

133. While the patching of data can be useful in certain circumstances, the Commission considers that the patching procedure and the criteria used to determine which data series to use in which circumstances – that is, what and when to patch – needs to be documented carefully, with supporting reasoning. A lack of such detailed documentation and support must be taken into consideration when evaluating analysis that relies on the patched data, in exactly the same way

[155] Exhibit 20414-X0256, EDTI-AUC-2016APR15-013(g), table on PDF page 50. Part of this difference arises because Dr. Meitzen calculates annual growth for the aggregated number of customers across all firms, whereas the Lowry study calculates annual growth separately for each firm and then averages these measures across firms.

[156] Exhibit 20414-X0396 (Brattle); Exhibit 20414-X0256, PDF page 41 (Meitzen).

[157] Exhibit 20414-X0417, spreadsheet replication of Lowry study by Dr. Meitzen using the patched customer count data utilized by Dr. Lowry, as described subsequently. Firms that are not common to the two studies are deleted, as described in footnote 140.

[158] See footnote 140.

[159] See footnote 95.

[160] The two sets of customer count data are provided in Exhibit 20414-X0100, in columns "AA" (Form 1) and "BD" (Form 861), and are reproduced in the Meitzen spreadsheet replication of the Lowry study, in Exhibit 20414-X0417, tab "Query1," with these same labelled columns and with the patched series used in the Lowry study in column "DF."

[161] Transcript, Volume 14, page 2845, line 5 to page 2846, line 2 (Dr. Meitzen).

[162] Examples include firms that experience very large customer count percentage increases in one year that are followed by almost equivalent large customer count percentage decreases in the following year(s). These are evident in Exhibit 20414-0417, the spreadsheet replication of the Lowry study by Dr. Meitzen. Specific examples include, but are not limited to, Niagara Mohawk Power Corporation, +32.2 per cent in 2001 and -35.7 per cent in 2003; and Green Mountain Power Corporation, +14.4 per cent in 2012, and -13.14 per cent in 2013.

OPG Interrogatory #3

Issue Number: 11.1
Issue: Is OPG's approach to incentive rate-setting for establishing the regulated hydroelectric payment amounts appropriate?

Interrogatory:

Reference: Exhibit M2 general

a) Please list and provide all studies of hydroelectric generation reviewed by PEG.
b) Please identify which of these studies use MW as an output and which use MWh.
c) Please identify which of these were used for regulatory purposes.

Response:

The following response was provided by PEG:

a-c) Table M2-11.1-OPG-3 below provides details of the studies that PEG reviewed. To the best of their knowledge, none of these studies were used for regulatory purposes.

Table M2-11.1OPG-3

Hydroelectric Generation Studies	**Outputs**	
	MWh	**MW**
Banfi, S., & Filippini, M. (2010). **Resource rent taxation and benchmarking – A new perspective for the Swiss hydropower sector.** *Energy Policy*, *38* (5), 2302-2308.	X	
Barros, C. P. (2008). **Efficiency analysis of hydroelectric generating plants: a case study for Portugal.** *Energy Economics*, *30* (1), 59-75.	X	
Barros, C. P., & Peypoch, N. (2007). **The determinants of cost efficiency of hydroelectric generating plants: A random frontier approach.** *Energy Policy*, *35* (9), 4463-4470.	X	X
Barros, C. P., Chen, Z., Managi, S., & Antunes, O. S. (2013). **Examining the cost efficiency of Chinese hydroelectric companies using a finite mixture model.** *Energy Economics*, *36*, 511-517.	X	X
Boucinha, J. M., Inácio, C. F., Gonçalves, A. C., & Gonçalves, A. V. (2015). **Measuring Efficiency of Portuguese Hydro Power Stations: DEA as a Tool for Internal Company Benchmarking.** *Coimbra Business Review*, *1* (1), 66-73.[1]	X	
Briec, W., Peypoch, N., & Ratsimbanierana, H. (2011). **Productivity growth and biased technological change in hydroelectric dams.** *Energy Economics*, *33* (5), 853-858.	X	X
Filippini, M., & Luchsinger, C. (2007). **Economies of scale in the Swiss hydropower sector.** *Applied Economics Letters*, *14* (15), 1109-1113.	X	
Filippini, M., Geissmann, T., & Greene, W. H. (2016). **Persistent and Transient Cost Efficiency – An Application to the Swiss Hydropower Sector** (Economics Working Paper 16/251). Switzerland: Centre for Energy Policy and Economics at the Swiss Federal Institute of Technology Zurich.	X	
Jha, D. K., & Shrestha, R. (2006). **Measuring efficiency of hydropower plants in Nepal using data envelopment analysis.** *IEEE Transactions on Power Systems*, *21* (4), 1502-1511.[2]	X	
lo Storto, C., & Capano, B. (2014). **Productivity changes of the renewable energy installed capacity: an empirical study relating to 31 European countries between 2002 and 2011.** *Energy Education Science and Technology Part A: Energy Science and Research*, *32* (5), 3061-3072.	X	
Sarica, K., & Or, I. (2007). **Efficiency assessment of Turkish power plants using data envelopment analysis.** *Energy*, *32* (8), 1484-1499.	X	
Sözen, A., Alp, I., & Kilinc, C. (2012). **Efficiency assessment of the hydro-power plants in Turkey by using Data Envelopment Analysis.** *Renewable Energy*, *46*, 192-202.	X	
Wang, B., Nistor, I., Murty, T., & Wei, Y. M. (2014). **Efficiency assessment of hydroelectric power plants in Canada: A multi criteria decision making approach.** *Energy Economics*, *46*, 112-121.[3]	X	X
Whiteman, J. (1999). **The potential benefits of Hilmer and related reforms: Electricity supply.** *The Australian Economic Review*, *32* (1), 17-30.	X	

[1] MWh is considered an output variable in this study, though it is not retained in the final three models.

[2] Installed capacity is not used as an output variable in this study. However, winter and summer peaking capacity are used as outputs; these are both measured as maximum power output (in MW) during the system peak.

[3] This study employs the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Outputs and inputs are not distinguished from each other (all are simply "indicators").

<u>Energy Probe Interrogatory #2</u>

Issue Number: 11.1
Issue: Is OPG's approach to incentive rate-setting for establishing the regulated hydroelectric payment amounts appropriate?

<u>Interrogatory</u>:

Reference: Exhibit M2

In Chart 1 at p.2 of its response to Undertaking JT3.24, LEI provided the annual TFP growth rate that it had calculated for each of the 16 companies for each of the 12 years in its sample:

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
OPG	-3.20%	5.90%	-5.30%	1.10%	-4.20%	11.10%	-1.70%	-16.70%	6.60%	-6.60%	6.10%	0.80%
AB Power	33.60%	-27.00%	0.40%	-37.40%	-82.80%	50.20%	97.00%	-51.40%	-12.00%	-19.20%	72.50%	-40.90%
AP Power	50.70%	-17.70%	-15.20%	-7.00%	-5.20%	-12.10%	19.60%	-6.40%	-3.30%	6.20%	13.80%	-33.30%
Ameren	-8.80%	30.40%	2.70%	-76.70%	46.80%	6.20%	2.60%	8.00%	-6.10%	-26.60%	21.00%	-23.70%
Avista	-14.80%	6.50%	-5.90%	12.40%	-11.30%	3.90%	-3.20%	-6.90%	24.30%	-9.60%	-14.20%	15.10%
Duke	21.50%	-26.70%	8.80%	-12.80%	-6.60%	4.70%	-1.30%	-2.90%	-10.80%	-6.30%	26.50%	-3.10%
GPA	50.70%	-35.70%	8.00%	-35.00%	-18.20%	-36.50%	110.30%	-22.20%	-13.40%	5.80%	65.10%	-38.10%
ID	1.70%	-2.90%	2.80%	39.40%	-40.40%	11.00%	16.30%	-10.00%	40.60%	-32.60%	-34.50%	9.40%
PacifiCorp	5.50%	-16.10%	-3.50%	36.50%	-21.70%	0.00%	-7.00%	8.30%	21.40%	-4.70%	-32.80%	20.40%
PG&E	10.30%	-7.40%	14.50%	17.80%	-61.00%	-0.30%	9.60%	16.10%	13.30%	-50.10%	-2.30%	-25.80%
Portland	-1.30%	3.30%	-9.40%	23.20%	-14.90%	0.10%	-1.10%	6.20%	7.70%	-9.80%	-14.90%	-4.90%
SCE&G	20.90%	12.20%	11.20%	-26.50%	8.00%	-13.90%	-3.70%	0.80%	-13.40%	6.70%	2.50%	-28.40%
Seattle	-12.90%	-1.10%	-7.50%	19.10%	-4.20%	-4.20%	-6.90%	-2.90%	28.30%	-9.70%	-16.80%	17.10%
SEPA	50.20%	-10.80%	12.20%	-58.70%	-0.90%	-17.20%	28.40%	14.80%	-13.90%	-11.40%	34.60%	-5.70%
SoCal	14.20%	-13.20%	37.20%	-2.50%	-70.10%	2.10%	33.50%	11.30%	9.60%	-48.70%	-20.80%	-24.30%
VA	6.60%	-14.30%	-20.60%	9.50%	15.00%	-40.50%	30.30%	19.80%	-12.50%	48.10%	-38.90%	-1.70%

LEI's Chart 1 also provides the average TFP growth over the entire 2003-2014 period for each company in its sample, referred to as the AVG. For example, the Chart shows that OPG's AVG was -0.49%.

a) Please confirm/disconfirm that OPG's AVG over the 12-year sample period is -0.51% rather than -0.49% as shown in Chart 1. Could the difference simply be due to rounding error? Are there any other instances of such error in Chart 1?

b) Please confirm/disconfirm that the mean of the 16 company AVG's is -1.01% and that the sample standard deviation is 2.37% (using the sample-variance formula in LEI's response to Undertaking JT3.24.

c) P.15 of the PEG reports states: "The productivity growth rates of individual companies tend to be more volatile than the average productivity growth of a group of companies". The data from Chart 1 above appear to support this statement. The sample standard deviation of the company AVG's is 2.37% (subject to check). However, the range of standard deviations of the individual company AVG's is 7.50% (for OPG) to 54.02% (for AB Power). (PEG may wish to confirm this range.) What accounts for this difference in volatility?

d) The LEI data in Chart 1 can also be averaged over the 12 company TFP's for each of the 16 years. For example, it appears that the mean TFP growth rate over all 16 companies was 14.56% for 2003 and -8.69% for 2004. Please confirm/disconfirm that the mean of those 12 year-averages is also -1.01, and that the sample standard deviation is 10.77%.

e) Taking all the 12-company TFP data for each of 16 years together, please confirm that the total number of TFP growth rate observations is 192, that the mean is -1.01% and that the standard deviation is 26.40%.

f) Please briefly discuss the relationship(s) among the standard deviation for the total sample of 192 observations (26.4%), the standard deviation of the 16 observations of company AVG's (2.37%) and the standard deviation of the 12 observations of the year-averages (10.77%).

g) If there is a relationship among the respective variances (rather than the standard deviations), what is that relationship? For example, can it be concluded that the variability in annual TFP growth rates is partly due to inter-company differences, and partly due to differences between business conditions in different years, apparently leaving a very large portion of the total variability unexplained?

h) What, in PEG's view, are the policy implications of adopting LEI's estimate of -1.01% when so much of the variability in its sample is, apparently, unexplained?

i) As LEI had done, please provide PEG's estimates of annual productivity growth for each company in its sample and for each year in its sample.

Response (Revised):

The following response was provided by PEG:

a) Confirmed. Yes, the difference could be due to rounding error. Yes, there are several other instances of such error. Please see the column labeled "Company AVG" in Tab 3 of Attachment M2-11.1-EP.

b) Confirmed. See tab 3 of Attachment M2-11.1-EP.

c) The Energy Probe calculations compare apples to oranges. PEG was saying that the average year to year growth rates of sample utilities are less volatile than the year to year growth rates of individual utilities.

d) Confirmed. See tab 3 of Attachment M2-11.1-EP

e) Confirmed. See tab 3 of Attachment M2-11.1-EP

f) The standard deviation of the total sample is larger than the standard deviation of the company AVG's and the standard deviation of the year-averages.

g) The relationship among the variances is similar to the relationship among standard deviations in the sense that the variance for the total sample (6.97%) is larger than the variance of the 16 observations of company AVG's (.06%), and the variance of the 12 observations of the year-averages (1.16%). Yes, that is a plausible interpretation of the data. However, it should be noted that both PEG and LEI set out to compute actual observed TFP trends of OPG's peers, not to fully explain the drivers of productivity growth.

h) The working papers provided in response to M2-11.1-OPG-1 contain year-by-year productivity growth rates for the individual companies in the sample.

The working papers file M2-11.1-OPG attachment PEG-WP-1.xlsx contains the results of the productivity calculations for each company and each year on worksheet "Indexes". The growth rates in the "Indexes" worksheet column AE are logarithmic.

PEG provided average annual productivity growth rate data by company for the 1996-2014 period in response to M2-11.1-SEC-2 attachment 1. The productivity values included an allocation of A&G expenses. It is not possible to produce these alternative results using the information in the working papers provided to all parties.

Ontario Energy Board

Ontario

EB-2010-0379

Report of the Board

Rate Setting Parameters and Benchmarking under the Renewed Regulatory Framework for Ontario's Electricity Distributors

Issued on November 21, 2013 and as corrected on December 4, 2013

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APPENDIX A: ALTERNATIVES RAISED IN CONSULTATIONS I

APPENDIX B: INFLATION FACTOR XVII

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2.2.1 Productivity Factor

In its RRF Report, the Board determined that the productivity factor will be based on Ontario electricity distribution industry TFP ("industry TFP") trends and should be derived from objective, data-based analysis that is transparent and replicable. Furthermore, the **Board determined that the productivity factor determination under the new Price Cap IR will continue to rely on the index-based approach**. The Board also stated its intention to update the productivity factor every five years (e.g., the update after 2014 would be in 2019).

The indexing method to estimating Industry TFP continues to be the most common basis for setting a productivity factor in rate setting formulas. In addition, the Board concludes that the approach is simpler than the alternative "econometric" approach proposed by Prof. Yatchew and therefore may be better understood by stakeholders and consumers.

The Board invited written comment on its intention to update TFP next in 2019.[14] Some stakeholders expressed concern over how this may impact distributors, particularly if it is applied to all distributors regardless of where they are in their IR term. The Board's approach is intended to provide greater certainty as to the time to achieve or surpass the external benchmark and retain any achieved savings. For distributors to benefit from that certainty, the industry benchmark needs to be in place for a reasonable period of time. The period of time generally used coincides with the IR plan term, and is a common feature of many IR plans. The Board is concerned that allowing for a change in the productivity factor midway through an IR term will erode the incentive benefits of providing stability and predictability in the achievable industry external benchmark. As such, **the Board has determined that the productivity factor will remain in effect until a distributor's next rebasing**. The stretch factor however will change annually,

[14] Ontario Energy Board. Letter to Stakeholders re: Update on Timeline for Expert Reports and Written Comments. May 30, 2013.

depending on the performance of the distributor, so as to add an additional incentive for distributors to improve performance year after year. This is addressed in section 4.1.

As detailed in the May 2013 Updated PEG Report, PEG calculated TFP trends using an index-based approach on Ontario data for the period 2002-2011.[15] PEG noted the results of the analysis were being materially impacted by outliers[16], Toronto Hydro and Hydro One, and recommended that the data for the two companies be excluded from the industry calculation. The Board agrees with PEG that an industry productivity measure reflective of 73[17] distributors operating in Ontario should not be materially impacted by only two distributors, and therefore will exclude the two outliers in the industry calculation. Furthermore, the Board is of the view that for as long as they remain outliers, these distributors should be excluded from the Industry TFP data set.

With the exclusion of the outliers, PEG also noted the results of its analyses showed a slowdown in productivity over the time period and expressed uncertainty of whether this trend would persist in the future. PEG and the other experts in this consultation expressed the view that the slow growth in Ontario Industry TFP may be attributable to the 2008-09 recession, a one-time event that is not expected to continue, as well as slow output growth, a factor which is expected to continue with Ontario's continued emphasis on conservation.

In section 4.5 of the Final PEG Report, PEG explained that because TFP growth will be part of the formula used to adjust base rates, only costs recovered through base rates should be included in the estimation of TFP growth. Table 5 in the Final PEG Report summarizes the cost measure used to estimate TFP. In brief, excluded costs include contributions in aid of construction and low voltage charges collected from embedded

[15] PEG has subsequently updated this analysis to include 2012 data, and those results are presented further below.
[16] An outlier is a value that "lies outside" (is much smaller or larger than) most of the other values in a set of data.
[17] Four distributors are excluded from PEG's analysis because their RRR data is not available: Attawapiskat First Nation; Fort Albany First Nation; Kashechewan First Nation; and Hydro One Remote Communities Inc.

distributors. PEG explains that including these costs in the TFP analysis would create a "mismatch" between the costs used as inputs for the rate adjustments and the costs that are actually subject to that rate adjustment. As explained in the Final PEG Report, it would not be appropriate for costs previously recovered outside of base rates to be reflected in the TFP trend, and therefore the rate adjustment mechanism, that will apply during an IR term. Doing so would mean increasing future customer rates to pay for costs that have already been recovered in previous customer rates.

TFP results changed dramatically when the analysis was updated to include 2012 data. While the results indicated an average annual industry TFP *growth* of 0.19% between 2002-2011, average annual industry TFP over the 2002-2012 period *declined* to -0.33%.

Such a dramatic change caused PEG to question the reasonableness of the data included in the analysis. When carrying out its updated TFP analysis to include 2012 data, PEG reported that OM&A expenses in 2012 were 11.14% higher than in 2011.[18] While there may be several reasons for the overall increase in OM&A, staff analysis identified that the largest changes appear to have been caused by three unusual and one-time events: the methodology of reporting in relation to OPA CDM program costs; the adoption of IFRS by some distributors again impacting on RRR reporting; and unusually large deferral account dispositions. The Board does not believe that any of these events should be included in the calculation of industry TFP such that they impact the long-run productivity of the sector. The first two identified events are a function of how data is reported to the Board by distributors. The last event is associated with the significant investment in smart meters in Ontario. For the purposes of estimating long-run TFP, PEG advised that these unusual and one-time events should be excluded from the TFP analysis.

[18] Pacific Economics Group Research, LLC. Empirical Research in Support Of Incentive Rate Setting in Ontario: 2012 Update. September, 2013. (http://www.ontarioenergyboard.ca/OEB/_Documents/EB-2010-0379/EB-2010-0379%202012_PEG_Report_on_Empirical_Work.pdf)

PEG subsequently adjusted its TFP analysis in order to remove the impact of:

- adoption of IFRS affecting amounts recorded on the balance sheet for fixed assets (NBV) as well as a reduction in depreciation and capitalized OM&A; and
- transfers of balances from deferral accounts to the balance sheet and income statement accounts, especially with respect to smart meters.

The Board will require corrections to distributor RRR balances for some distributors in order to isolate OPA CDM program costs from the TFP analysis. The Board will issue a request to distributors and undertake the associated corrections in due course such that any updates may be reflected in the 2019 TFP calculation.

PEG also expressed concern over the reasonableness of implementing a negative productivity factor for rate setting given the regulatory environment in Ontario. PEG advised stakeholders that the potential for further revenue decoupling, the continued use of rate riders and/or deferrals, and the introduction of choice under RRF of rate setting approaches create a significant probability that a negative productivity factor would either include costs that are already being recovered elsewhere, or reflect the experience of a small number of distributors with atypical investment needs who will likely opt out of Price Cap IR in favour of a Custom IR approach. This latter result, PEG observed, would be counter to the Board's intended purpose of Price Cap IR, which is to be appropriate for most distributors in the Province who do not have high or variable capital requirements. Because of these concerns, PEG recommended that the productivity factor in Price Cap IR be set at zero.

At the Conference, stakeholders generally agreed that while the Board could spend more time trying to understand the negative TFP growth in Ontario, it may not be a productive study of the current data given the extent of analysis that has already been undertaken. However, Prof. Yatchew suggested that going forward progress may be

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Table 383-0026 [1]

Multifactor productivity and related variables in the aggregate business sector and major sub-sectors, by North American Industry Classification System (NAICS), provinces

annual (index, 2007=100)

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The data below is a part of CANSIM table 383-0026. Use the Add/Remove data tab to customize your table.

Selected items [Add/Remove data]

Labour productivity measures and related measures = Multifactor productivity [2]

Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014
Newfoundland and Labrador	Business sector industries [1]	89.082	87.130	75.844	76.385	70.163
	Agriculture, forestry, fishing and hunting [16]	124.339	123.078	120.418	124.971	113.687
	Mining and oil and gas extraction [17]	75.353	71.511	51.907	52.331	42.267
	Utilities [22]	116.605	120.540	105.488	98.956	89.796
	Construction [23]	100.642	103.285	100.082	100.032	117.881
	Manufacturing [18]	113.275	94.244	122.697	116.564	114.003
	Wholesale trade [41]	102.999	116.324	126.746	135.241	143.293
	Retail trade [44-45]	110.664	111.507	110.976	112.382	113.122
	Transportation and warehousing [48-49]	93.356	90.195	91.963	92.287	91.715
	Information and cultural industries [51]	151.357	161.630	177.321	213.148	214.543

Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014
	Finance, insurance, real estate, rental and leasing and management of companies and enterprises [19]	99.025	98.255	100.993	104.999	107.055
	Professional, scientific and technical services [54]	100.526	104.656	97.567	97.237	102.089
	Administrative and support, waste management and remediation services [56]	102.809	101.240	107.589	117.282	118.739
	Arts, entertainment and recreation [71]	125.142	124.012	118.040	131.273	115.304
	Accommodation and food services [72]	108.967	111.186	108.309	107.967	102.261
	Other private services [20]	104.544	99.548	95.671	99.331	100.109
	Business sector, goods, special aggregation [21]	82.157	78.824	63.415	63.042	55.455
	Business sector, services, special aggregation [22]	107.135	108.154	109.373	112.648	113.737
Prince Edward Island	Business sector industries [1]	100.555	98.153	97.687	98.880	99.559
	Agriculture, forestry, fishing and hunting [16]	109.470	100.411	104.708	99.426	103.665
	Mining and oil and gas extraction [17]	83.311	81.561	140.544	156.930	156.805
	Utilities [22]	123.550	130.450	128.962	121.223	117.661
	Construction [23]	94.816	94.346	87.141	88.714	87.036
	Manufacturing [18]	94.199	90.766	94.398	103.868	112.646
	Wholesale trade [41]	83.647	99.186	101.733	99.347	102.313
	Retail trade [44-45]	103.863	98.311	96.988	96.585	99.157
	Transportation and warehousing [48-49]	104.510	109.406	110.324	106.237	109.319
	Information and cultural industries [51]	101.807	102.284	101.515	98.830	94.278

North American Industry

Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014
	Finance, insurance, real estate, rental and leasing and management of companies and enterprises [19]	98.920	99.197	102.743	104.935	107.272
	Professional, scientific and technical services [54]	96.503	96.010	96.169	98.768	99.828
	Administrative and support, waste management and remediation services [56]	88.962	89.527	90.228	90.193	91.691
	Arts, entertainment and recreation [71]	88.785	92.635	91.559	91.069	92.508
	Accommodation and food services [72]	95.772	93.360	92.133	94.774	94.817
	Other private services [20]	99.200	103.726	103.013	101.975	106.109
	Business sector, goods, special aggregation [21]	97.846	98.497	97.369	96.300	97.919
	Business sector, services, special aggregation [22]	98.598	99.840	100.223	101.674	104.251
Ontario	Business sector industries [1]	97.594	98.967	99.399	100.093	102.887
	Agriculture, forestry, fishing and hunting [16]	110.803	112.240	113.871	117.661	118.264
	Mining and oil and gas extraction [17]	73.503	80.825	69.394	69.124	65.519
	Utilities [22]	93.775	87.548	84.728	89.187	90.703
	Construction [23]	91.164	90.290	85.280	82.544	81.292
	Manufacturing [18]	97.561	101.737	106.225	107.089	113.279
	Wholesale trade [41]	98.862	105.403	107.719	110.485	116.750
	Retail trade [44-45]	102.833	100.368	98.951	99.508	102.264
	Transportation and warehousing [48-49]	95.058	95.912	91.789	92.092	92.885
	Information and cultural industries [51]	107.280	109.251	112.788	120.629	122.660
Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014

	Finance, insurance, real estate, rental and leasing and management of companies and enterprises [19]	99.003	100.932	102.236	103.864	107.316
	Professional, scientific and technical services [54]	98.007	96.369	98.820	97.148	101.611
	Administrative and support, waste management and remediation services [56]	95.549	94.650	95.054	93.774	93.048
	Arts, entertainment and recreation [71]	100.057	97.752	98.852	100.423	102.537
	Accommodation and food services [72]	101.071	100.755	100.113	99.857	103.307
	Other private services [20]	97.879	98.074	97.508	99.707	103.486
	Business sector, goods, special aggregation [21]	96.346	98.546	98.606	98.491	100.904
	Business sector, services, special aggregation [22]	98.906	99.935	100.490	101.715	104.700
Manitoba	Business sector industries [1]	100.382	101.203	101.169	102.861	102.612
	Agriculture, forestry, fishing and hunting [16]	98.456	80.999	100.298	113.673	94.024
	Mining and oil and gas extraction [17]	85.616	80.835	75.711	64.566	54.142
	Utilities [22]	78.081	76.951	72.643	78.535	75.224
	Construction [23]	120.035	112.065	109.148	109.759	126.243
	Manufacturing [18]	99.423	104.615	105.921	112.150	108.992
	Wholesale trade [41]	104.506	105.163	101.741	102.435	108.799
	Retail trade [44-45]	104.200	105.653	102.580	105.829	106.240
	Transportation and warehousing [48-49]	96.274	98.139	99.476	101.287	105.055
	Information and cultural industries [51]	111.413	117.272	116.115	118.104	125.319
Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014

	real estate, rental and leasing and management of companies and enterprises [19]					
	Professional, scientific and technical services [54]	102.212	105.024	104.034	105.207	102.735
	Administrative and support, waste management and remediation services [56]	92.116	96.584	95.769	94.248	93.712
	Arts, entertainment and recreation [71]	104.161	105.134	106.412	102.973	102.356
	Accommodation and food services [72]	98.376	96.352	96.724	100.081	102.322
	Other private services [20]	96.348	94.686	97.369	98.912	101.431
	Business sector, goods, special aggregation [21]	93.461	95.354	93.506	95.283	96.438
	Business sector, services, special aggregation [22]	97.025	100.012	100.375	100.431	101.621
British Columbia	Business sector industries [1]	94.656	96.944	96.081	97.149	99.124
	Agriculture, forestry, fishing and hunting [16]	102.645	114.990	111.853	123.513	115.669
	Mining and oil and gas extraction [17]	86.026	79.597	68.846	69.608	67.923
	Utilities [22]	66.825	72.736	74.208	72.121	67.631
	Construction [23]	106.669	107.921	110.365	107.628	109.857
	Manufacturing [18]	95.590	99.728	99.282	102.102	104.525
	Wholesale trade [41]	95.383	99.945	102.172	103.907	106.359
	Retail trade [44-45]	98.808	99.513	98.916	101.579	105.856
	Transportation and warehousing [48-49]	97.270	100.894	102.916	105.010	108.270
	Information and cultural industries [51]	93.261	92.809	96.252	94.703	97.918

Geography	North American Industry Classification System (NAICS)	2010	2011	2012	2013	2014
	Finance, insurance, real estate, rental and	96.620	98.181	95.852	98.531	101.372

	real estate, rental and leasing and management of companies and enterprises [19]					
	Professional, scientific and technical services [54]	95.738	97.950	100.052	100.313	105.022
	Administrative and support, waste management and remediation services [56]	97.649	100.378	101.895	105.526	106.564
	Arts, entertainment and recreation [71]	93.688	92.339	93.447	92.793	95.499
	Accommodation and food services [72]	92.691	95.158	90.309	92.477	97.425
	Other private services [20]	88.669	94.582	92.407	94.932	96.694
	Business sector, goods, special aggregation [21]	95.325	96.573	93.816	93.830	93.387
	Business sector, services, special aggregation [22]	95.091	97.705	97.501	99.362	102.447

Footnotes:

1. The business sector covers the whole economy less public administration, non-profit institutions and the rental value of owner-occupied dwellings.
2. Multifactor productivity measures the efficiency with which all inputs are used in production. It is the ratio of real gross domestic product (GDP) to combined labour and capital inputs.
3. Labour productivity is measured as real gross domestic product (GDP) per hours worked. It shows the time profile of how productively labour is used to generate value-added. Changes in value-added-based labour productivity reflect the joint influence of capital, skill upgrading, and overall productive efficiency.
4. Capital productivity is measured as real gross domestic product (GDP) per unit of capital services.
5. Real gross domestic product (GDP) (or real value-added) is a chained Fisher quantity index of gross domestic product (GDP) at basic prices.
6. Labour input is obtained by chained-Fisher aggregation of hours worked of all workers, classified by education, work experience, and class of workers (paid workers versus self-employed and unpaid family workers) using hourly compensation as weights.
7. The number of hours worked in all jobs is the number of all jobs times the annual average hours worked in all jobs. According to the retained definition, hours worked means the total number of hours that a person spends working, whether paid or not. In general, this includes regular and overtime hours, breaks, travel time, training in the workplace and time lost in brief work stoppages where workers remain at their posts. On the other hand, time lost due to strikes, lockouts, annual vacation, public holidays, sick leave, maternity leave or leave for personal needs are not included in total hours worked.
8. Labour composition is the ratio of labour input to hours worked. Changes in labour composition reflect the shifts in the educational attainment and work experience of the workforce.
9. Capital input measures the services derived from the stock of fixed reproducible business assets (equipment and structures). It is obtained by chained-Fisher aggregation of capital stocks using the cost of capital to determine weights.
10. Combined labour and capital inputs are obtained by chained-Tornqivst aggregation of labour and capital input using cost shares of labour and capital as weights.
11. Gross domestic product (GDP) is valued at basic prices. It is calculated as gross output at basic prices minus intermediate inputs at purchaser prices. Data on gross domestic product (GDP) are available up to the most current year of the input-output table.
12. Labour compensation consists of all payments in cash or in kind made by domestic producers to workers for services rendered - in other words, total payroll. It includes the salaries and supplementary

labour income of paid workers, plus an imputed labour income of self-employed workers.

13. Capital cost represents the surplus-profits, depreciation, rent, and net interest-intended as compensation to the owners of capital. It is calculated as nominal gross domestic product (GDP) at basic prices minus labour compensation. Data on capital income are available up to the most current year of the input-output table.

14. Contribution of capital intensity to labour productivity growth is calculated as the growth in capital services per hour times capital's share of nominal gross domestic product (GDP). It reflects the effects of capital investment on labour productivity growth.

15. Contribution of labour composition to labour productivity growth is calculated as the growth rate of labour composition times labour's share of nominal gross domestic product (GDP). It reflects the effects on labour productivity growth of skill upgrading as measured by increases in the experience and education composition of the workforce.

16. This combines the business establishments of the North American Industry Classification System (NAICS) code 11.

17. This combines the business establishments of the North American Industry Classification System (NAICS) code 21.

18. This combines the business establishments of the North American Industry Classification System (NAICS) codes 311-316, 321-327, 331-337, 339.

19. This combines parts of the North American Industry Classification System (NAICS) codes 52, 53, 55. This aggregate excludes the imputed rent of owner occupied dwellings.

20. This combines parts of the North American Industry Classification System (NAICS) codes 61, 62, 81.

21. This combines the North American Industry Classification System (NAICS) codes 11, 21, 22, 23, 31-33.

22. This combines the North American Industry Classification System (NAICS) codes 41, 44-45, 48-49, 51, 52, 53, 54, 55, 56, 61, 62, 71, 72, 81 with the exception of owner-occupied dwellings industry.

Source: Statistics Canada. *Table 383-0026 - Multifactor productivity and related variables in the aggregate business sector and major sub-sectors, by North American Industry Classification System (NAICS), provinces, annual (index, 2007=100 unless otherwise noted),* CANSIM (database). (accessed:)
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Date modified: 2016-09-12

Table 5A

Reconciling LEI and PEG Productivity Results

	Average Annual Growth	
	MFP	Output Quantity
LEI methodology (2003-2014)		
As stated (capacity used as capital input)	-1.01%	-0.64%
With common US sample	-1.38%	-0.99%
Add estimated impact from using PEG Form 1 MWh data (+0.05%)	-1.33%	-0.94%
With capacity used as both output and capital input	-0.19%	0.19%
PEG methodology including a one-hoss shay (1HS) capital quantity index and capacity as output		
With a common sample	-0.32%	0.41%
With an expanded sample	-0.66%	0.39%
PEG methodology including a geometric decay (GD) capital quantity index		
With volume as output (2003-2014)	-1.70%	-1.64%
With capacity as output (2003-2014)	0.33%	0.39%
With a longer time periods and capacity as output index		
1996-2014	0.47%	0.22%
1975-2014	1.06%	1.49%
With an expanded sample of US IOUs and capacity as output index		
2003-2014	0.05%	0.38%
1996-2014	0.29%	0.20%
1975-2014	0.94%	1.40%
OPG productivity trends		
Calculated from LEI workpapers	-0.49%	-0.87%
With a one-hoss shay capital quantity index and capacity as output	-0.24%	0.06%
With capacity as output and a GD capital quantity index	0.28%	0.06%
1996-2014 trend	1.07%	0.51%
1985-2014 trend	1.24%	0.34%

Table 6A

OPG's Productivity Growth Using Capacity as Output and a One-Hoss Shay Capital Quantity Index[1]

	Generation Capacity (MW)	O&M Cost	O&M Price	Input Quantities		PFP O&M		PFP Capital		Weights		MFP
				O&M	Capital	Index	Growth	Index	Growth	O&M	Capital	Growth
2002	6,384	109,088	1.000	109,088	35,103,778	1.000		1.000		6%	94%	
2003	6,409	120,945	1.022	118,382	35,087,849	0.925	-7.8%	1.006	0.6%	6%	94%	0.1%
2004	6,439	122,341	1.046	116,908	34,485,436	0.941	1.7%	1.027	2.1%	7%	93%	2.0%
2005	6,407	131,759	1.079	122,146	34,567,137	0.896	-4.9%	1.019	-0.7%	8%	92%	-1.0%
2006	6,451	144,915	1.099	131,830	33,975,362	0.836	-6.9%	1.044	2.4%	11%	89%	1.5%
2007	6,450	152,640	1.135	134,431	34,025,768	0.820	-2.0%	1.042	-0.2%	12%	88%	-0.4%
2008	6,477	171,873	1.163	147,807	33,978,568	0.749	-9.1%	1.048	0.5%	11%	89%	-0.6%
2009	6,390	171,279	1.177	145,469	33,766,724	0.751	0.2%	1.041	-0.7%	14%	86%	-0.6%
2010	6,390	170,905	1.210	141,195	33,543,808	0.773	3.0%	1.048	0.7%	16%	84%	1.0%
2011	6,422	174,611	1.232	141,787	33,511,074	0.774	0.1%	1.054	0.6%	16%	84%	0.5%
2012	6,422	178,134	1.250	142,489	33,562,454	0.770	-0.5%	1.052	-0.2%	19%	81%	-0.2%
2013	6,433	182,584	1.270	143,719	33,395,313	0.765	-0.7%	1.059	0.7%	16%	84%	0.4%
2014	6,433	188,020	1.296	145,026	35,639,377	0.758	-0.9%	0.993	-6.5%	14%	85%	-5.6%
2015					34,209,628							
Average Annual Growth Rates												
2003-2014	**0.06%**	**4.54%**	**2.16%**	**2.37%**	**0.13%**		**-2.31%**		**-0.06%**	**13%**	**87%**	**-0.24%**
2003-2013	**0.07%**	**4.68%**	**2.18%**	**2.51%**	**-0.45%**		**-2.44%**		**0.52%**	**12%**	**88%**	**0.26%**

[1] Growth rates are calculated logarithmically.

- The NERA/Utilities method essentially estimates the trend in the *total* number of employees rather than the trend in distribution *O&M* employees, which is what we care about. The total number of employees includes construction employees, which are counted implicitly in the capital quantity index.

- The trend in the *total* number of employees does not take account of changes in the *composition* of employees over time.

- The NERA/Utilities method uses the share of distribution salaries and wages in *total* salaries and wages.[15] Total salaries and wages includes an allocation to clearing accounts. In other words, the denominator includes expenses that have not been allocated to a utility function (generation, transmission, etc.). The distribution share is thus understated.

All of these problems can be sidestepped by using the residual approach set forth in equation [1] in *all* years of the sample period, as PEG did in its research for the CCA. I should also note that in our application of the residual method we regionalize the labor price trend.

Some of the productivity research methods you propose for X factor calibration seem tailored to the circumstances of Alberta utilities. Do you often customize your productivity research methods to be relevant to the utilities to which they apply?

Yes. For example, I tend to consider *revenue*-weighted output indexes that include volumes by *some* means when utilities will likely be subject to *price* caps, and the number of customers when they are likely to be subject to *revenue* caps. In work for utilities in the northeast United States, I have throughout my career tended to use northeast utility peer groups.

[15] They could instead have used the share of distribution salaries and wages in the sum of all salaries and wages *assigned directly to utility functions*.

I have in recent years featured the COS approach to measuring capital cost in my US research and testimony. This reflects the fact that US utilities often propose *macroeconomic* inflation measures such as the GDPPI in the rate (or revenue) cap escalator. This raises the issue of how well these measures track input price trends of utilities. The COS approach to measuring capital cost sheds more light on this issue than the GD or one hoss shay approaches. In this proceeding, I have instead featured the GD approach because a more customized measure is more likely to be used for inflation in next generation PBR, and the GD approach is simpler and easier for other parties to review. In future proceedings, MFP calculations using GD can be presented on a spreadsheet if parties so desire.[16]

Are there other reasons why your methodology may change from time to time?

Yes. My opinions concerning best practices in X factor calibration have naturally evolved over the years. For example, I now use a custom M&S price index rather than the GDPPI when calculating the M&S quantity trend. I have greater appreciation for the usefulness of the GD approach to capital costing in Canadian proceedings.

This Commission ruled in paragraph 337 of Decision 2012-237 that "the TFP estimate that informs the X factor is supposed to reflect industry growth trends, not the trends in Alberta alone or among a group of companies with similar operations and cost levels to those in Alberta." Why then have you tried to customize your approach to X factor calibration in this proceeding?

My reading of this paragraph is that the Commission felt that business conditions that were different in Alberta but affected the *level* of costs rather than their *trends* were not grounds for X factor customization, and I generally agree. However, some business conditions may be unusual in Alberta that affect productivity *trends*. Or, as in the case of the

[16] We did not do this in this proceeding because the COS approach to capital costing is also used and is more difficult to place on a spreadsheet.

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Estimating Capital Inputs for Productivity Measurement: An Overview of Concepts and Methods

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Estimating Capital Inputs for Productivity Measurement: An Overview of Concepts and Methods

by Michael J. Harper

Introduction

Productivity measurement involves comparing trends in output with trends in inputs. The microeconomic theory of the firm uses a *"production function"* to formally describe the relationship between inputs and output. In its simplest form[1], a production function treats inputs as if they are consumed in the production of outputs. Capital is, of course, one type of input. However, capital goods do not neatly conform with the simple production model. Among other things, they are not consumed in production.[2] Nonetheless, capital goods must specifically be deployed in production for a period of time in order to *render services*. A measure of capital input which would be consistent with theory is therefore the quantity of the *flow of services* provided by capital goods.

The capital service flow is a rather abstract notion and it is rarely possible to measure it directly.[3] Instead, estimation of the service flow depends on applying theory to related information which is more readily obtained such as data on investment. This estimation process depends on a careful analysis of the relationship between capital services and the goods which produce them. The approach used by the U.S. Bureau of Labor Statistics (BLS) to measure multifactor productivity[4] (MFP) is in close conformance with the literature on productivity measurement based on the *neoclassical* production model.[5]

Neoclassical theory deals with the difficult problem of how to treat capital services in a production function. This theory involves a set of assumptions. First, the quantity of capital services is defined in terms of investment goods. Second, investors are assumed to have perfect foresight regarding the future results of their investments. Finally, investment behaviour is assumed to be

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1 One simple production function, f, expresses the relationship as $Y = f(x^1, x^2, ..., x^n, t)$ where Y is the quantity of output, x^i are quantities of inputs, and t is a time index. Productivity growth occurs as f shifts outward over time.

2 This is a property capital shares with labor!

3 The owner and user of a capital asset are often the same firm. When this is the case, we do not observe a transaction for capital services.

4 This is the approach BLS uses to measure "multifactor productivity" (MFP). MFP is often referred to as "total factor productivity". MFP involves comparing output with several inputs rather than just labor input. For the US private nonfarm business sector, BLS publishes measures of real final output per combined unit of capital and labor input. For more specific industries including total manufacturing, BLS publishes real "sectoral" output per combined unit of capital, labor, and purchased intermediate inputs of energy, materials, and services. The most recent report which summarizes and presents these measures is BLS [1996].

5 In this paper, we will speak of the neoclassical "model" or "procedures" for measuring capital or productivity. We will be referring to a somewhat loosely defined scholarly line, with origins in works by Paul Samuelson [1947] and Robert Solow [1957], and culminating in a book by Dale Jorgenson, Frank Gellop and Barbara Fraumeni [1987]. While there are differences between the BLS procedures and those of Gellop, Jorgenson, and Fraumeni, many of the most important concepts are similar.

track of quality change falls on the price deflator.[19] Thus, the real investment stream which enters equation (1) must be adjusted to reflect any quality improvements as "more investment". Furthermore, the burden of accounting for the deterioration and the services of a good as it ages and of the effects of obsolescence fall on the age/efficiency function, s_τ[20].

Calculation of $K_{i,t}$ using equation (1) requires that we maintain a *set of vintage accounts,* that is, we must keep track of how much investment occurred in each past year for each asset type.

A simpler PIM formula which is commonly used is:

$$K_{i,t} = I_t + K_{i,t-1}\,(1-\delta). \qquad (2)$$

Equation (2) is easier to compute than equation (1) because it is recursive. While the answer depends on historical investments, the formula does not reference the entire investment stream each year.

The drawback to equation (2) is that it imposes a constant rate of deterioration on the efficiency function, ie. $s_\tau=(1-\delta)^\tau$[21]. It is not possible to describe some plausible age/efficiency profiles in terms of a constant pattern of deterioration. A good illustrative example is that of a light bulb. It deteriorates very little (if any) through most of its lifetime, That is, its services (converting electricity into light) remain nearly constant. Then, one day, it burns out, after which it has no value whatsoever.

While the light bulb is an extreme example (and often too short-lived to be considered capital), many assets appear to provide nearly constant service flows during their initial years. Automobiles are one example. Even though automobile resale values decline rapidly (depreciate) during the first three years of their service lives, two and three year old autos are often as nice looking and reliable as new ones. In other words, their services do not deteriorate very rapidly. Why, then, do their values depreciate? The depreciation reflects the buyers expectations of the *future* services the auto will provide. Buyers and sellers are evidently quite aware that a three year old auto will become unreliable much sooner than a new one, even if it is presently in "good condition".

[19] Suppose the price of a new asset in year t is \$1.00, and that a similar asset is improved by 5% by year t+1, and that the price of the improved asset is \$1.08. The new asset, like the old, will be weighted with an efficiency function of 1.00 the year it is created. In order to preserve the notion of a quantity index, we need to have the new asset count as 1.05 units of investment. Since we are measuring investment by deflating nominal expenditures, the price index must rise 3 percent between the two years in order to ensure this result.

[20] Robert Mall [1968] discusses the theoretical properties of the aggregate capital measure.

[21] This is also known as geometric decay, which is the discrete counterpart to exponential (Beta) decay. Harper [1983] concludes that geometric decay is in many cases unrealistic.

The distinction between depreciation and deterioration corresponds to the distinction between the value of a capital good and its service flow. The fundamental neoclassical assumption, that the value of an asset equals the discounted value of future services (rents), addresses precisely this issue, At BLS, what we have concluded from this is that, for productivity measurement, we want the specification of s_τ to reflect an asset's efficiency profile and not its price profile. To emphasize that our measures are constructed with productivity measurement in mind, we have dubbed them "productive capital stocks." We sometimes refer to capital stocks constructed from age/price profiles as "wealth stocks".

When we settled on our procedures in 1983, we decided to use equation (1), rather than the simpler constant rate of deterioration model, because we felt the later was unrealistic for most asset types. The difficulty this left us with is that the best available datum on aging capital was often an estimate of its rate of depreciation. While we have found data related to services in a few cases[22], they are fairly scarce. We have made use of estimates of service lives made by BEA in most cases. At BLS we use a flexible form[23] for the age/efficiency profile, and then use evidence on service lives, and depreciation rates to set the parameters of that form. We have selected forms which decline gradually early in an asset's life, and then more rapidly later in its life.

During the past couple of years, BEA has been doing research to change its service life estimates to conform with evidence on rates of economic depreciation which appear in the literature. While we have not yet received their final study, our plan is to use this information to adjust our service life estimates, Neoclassical theory predicts that each age/efficiency profile will have a specific associated age/price profile which is "dual" to it. At BLS, we hope to use BEA's information to adjust our age/efficiency profiles to ensure that they predict age/price patterns which are consistent with the new evidence assembled by BEA.

While equation (2) affords some flexibility, the assumption that efficiency is a fixed function of age is fairly rigid. Unfortunately, it is difficult to avoid this assumption owing to the paucity of data.[24]

[22] We made use of some data on miles driven by commercial trucks by age in BLS [1983] as described on p. 44.

[23] We use a hyperbolic formula for efficiency, $s_\tau=(L-\tau)/(L-B\tau)$, Where L is the service life, t is the age of the asset and B is a parameter. By varying B, the graph of this function can take on various shapes. For B=1 we have "one hose shay" capital and for B=0 we have straight line deterioration. For 0<B<l the function is "concave" to the origin and for B<0 the function is convex, similar to the shape of a geometric decay curve. BLS assumes B=.5 for equipment and B=.75 for structures. BLS also assumes that, for each type of asset, service lives are normally distributed about a mean because discards do not occur a fixed number of years after investment. A more extensive discussion of these subjects can be found in Appendix C of BLS(1983), in Harper [1983], and in Powers [1989].

[24] Ball and Harper [1990] were able to relax this assumption and others using a database on dairy and beef cattle assembled by the U.S. Department of Agriculture. It is hard to imagine finding the right data to do similar work for equipment or structures.