EMPIRICAL ANALYSIS OF TOTAL FACTOR PRODUCTIVITY TRENDS IN THE NORTH AMERICAN HYDROELECTRIC GENERATION INDUSTRY

Prepared for

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1 Executive Summary

On March 28, 2013, the Ontario Energy Board ("OEB") published a report outlining its policy for implementing incentive ratemaking ("IR") for OPG's prescribed assets. With this in mind, London Economics International ("LEI") was engaged by OPG to perform a Total Factor Productivity ("TFP") study. The purpose of this report is to share findings from LEI's TFP study, which estimated TFP trends for a select group of peers from the North American hydroelectric generation industry.

This report is structured as follows: Section 2 presents a background into the key events that led to this study. Section 3 presents an overview of the various methods of measuring productivity, and explains why the TFP index method was selected for this study. Section 4 introduces the different inputs and outputs that could be used in the TFP index, and explains LEI's choice. Section 5 goes over the data gathering process for the peers that made up the industry used in the TFP study. Section 6 presents the results of the TFP study, and Section 7 provides concluding remarks.

1.1 What is TFP?

Total factor productivity measures the total quantity of outputs of a firm relative to the quantity of inputs it employs. TFP must cover all material inputs to production, and core outputs of a firm. TFP focuses on quantities, not costs,[1] and measures the year-on-year changes in overall productivity for the firm and its peers. It is important to note that it does not consider efficiency levels, and is therefore not a benchmarking study. An industry TFP study by definition will **not** focus on the regulated firm. The TFP study, by its nature, is also backward looking - reporting historical growth rates or trends in productivity for selected firms or the industry as a whole. A growth rate reflecting multiple years (preferably 10 years or longer) is the primary result reported in an industry TFP study.[2]

1.2 What data was used for the TFP study?

Based on best practices of estimating TFP for generation companies, and after considering issues related to data availability, LEI defined the TFP study output as generation in megawatt hours ("MWh"), and inputs as physical capital measured in megawatts ("MW"), as well as

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[1] While costs are not the focus of a TFP study, they are still needed to form input weights; this is described further in Section 4.2.2.

[2] LEI notes that there is no precedent for TFP studies of hydroelectric generation businesses for purposes of regulatory ratemaking. This is not surprising as generation is not typically regulated using IRM. However, TFP based empirical studies do exist for generation in academia.

annual operations and maintenance ("O&M") costs measured in dollars and deflated by an appropriate index in order to isolate productivity trends.[3]

The data selection and gathering process was the most significant challenge in conducting the TFP study. Primary data sources include FERC Form 1, EIA, US BEA, US BLS, StatsCan, and company public reports, as well as data provided directly by OPG. The final TFP study includes 17 firms in total: OPG, 14 US investor-owned firms that file FERC Form 1 data, and 2 US federal and municipal operators. Data for this study covered an eleven year period from 2002-2012.[4]

1.3 What are the results of the TFP study?

For the industry consisting of OPG and 16 US peers, using data from 2002-2012, the TFP growth rate was estimated to be -1.02% per annum using the 'average growth' method. Under the 'trend regression' method, the industry TFP growth rate was estimated to be -1.00% per annum.[5] As explained further in Section 6.2.1, negative TFP results can be expected for mature hydroelectric businesses, because of fixed production assets, fixed production capabilities, and rising asset maintenance costs over time.

To determine these TFP figures, LEI used a Chained Fisher Ideal index method with a model consisting of two inputs (capital and O&M) and a single output (generation), as described further in Section 6.1.

1.4 How should the results of the TFP study be used for rate setting?

An industry TFP study measures the changes in overall productivity for a particular industry or peer group over a specified time period. Because an industry TFP study reports historical productivity growth rates, care must be applied to ensure that going forward business conditions are similar to those that prevailed historically. An industry TFP is **not** a benchmarking study, as it does not focus on efficiency levels; therefore, it is important that TFP results are not viewed in the same way as a benchmarking study. This also means that individual TFP results should not be viewed self-referentially or compared to the industry result.[6]

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[3] See Section 4 for details on how this data is used and Section 4.2.1 for details on the deflation index.

[4] At the time LEI began this study, 2013 data was not yet available.

[5] See Section 3.2.2 for description of the two different methods of measuring TFP growth trends.

[6] The use of an industry rate as opposed to an individual rate is important due to the fact that it has better incentive properties. This is because the regulated firm in question cannot readily influence the result, and also because it reduces data error risk.

In the OEB report on Rate Setting Parameters and Benchmarking (EB-2010-0379) issued on November 21, 2013, the Board stated that the it will continue with a price cap formula and the use of an I-X regime.[7] Specifically, the Board has stated it would continue to rely on an index-based approach to determine productivity gains or the X-factor. In this respect, the methodology used by LEI employs an index-based methodology. The results from this study will be useful to inform the productivity growth rate assumptions under an I-X regime.[8]

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[7] OEB. *Rate Setting Parameters and Benchmarking under the Renewed Regulatory Framework for Ontario's Electricity Distributors.* Issued November 21, 2013, corrected December 4, 2013.

[8] This process through which TFP studies could be used to inform growth rate assumptions under an I-X regime is explained further in section 3.1.

2 Background

Under *Regulation 53/05* pursuant to Section 78.1 of the *Ontario Energy Board Act*, 1998, the OEB's mandate includes setting payments for prescribed assets (nuclear and hydroelectric) of OPG which to date have been under a cost of service ("COS") regulation.[9] In 2012, the OEB started stakeholder consultations to consider incentive regulation options for OPG's prescribed assets. On March 28, 2013, the OEB published a report outlining its policy directive and next steps for implementing IR for OPG's prescribed assets.[10] One of these directives to OPG was to file a work plan and a status report for an independent productivity study in the next application to set payment amounts.

To fulfill the OEB mandate, OPG retained LEI in late 2013 to perform an industry productivity study for OPG's prescribed hydroelectric assets. LEI's scope of work included identification of appropriate methodologies of data compilation and peer selection, as well as empirical analysis. This report addresses all sections of the work plan.

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[9] OEB. *Ontario Energy Board Act, 1998*. <http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_98o15_e.htm>

[10] OEB. *Incentive Rate-making for Ontario Power Generation's Prescribed Generation Assets EB-2012-0340*. March 28, 2013.

3 Basics of Total Factor Productivity

3.1 What is productivity?

Productivity is the ratio of the quantity of outputs produced by a firm, to the quantity of inputs used by the firm. Productivity growth is a trend variable, based on the year-on-year change in the productivity ratio, or the rate of growth in quantity of outputs relative to the rate of growth in the quantity of inputs. For purposes of IR, and specifically in the design of price caps and revenues caps, regulators are interested in changes in productivity over time. For example, historical productivity growth can inform regulators and the regulated utility on the level of productivity change, to guide the choice of an explicit productivity target or X factor under an I-X price cap or revenue cap.

Note that there are multiple methods for measuring productivity. In a practical sense, productivity measures the output quantity relative to input quantity, while productivity growth defines changes in this measurement over time. Common drivers of increased productivity include technological progress, economies of scale, and scope. When attempting to measure productivity, one would seek to capture as many drivers as possible. It should be noted that while TFP indexing techniques can be relied upon to measure total productivity, a TFP value cannot be decomposed to analyze the individual components or drivers of productivity.

There are also multiple categories of productivity that could be measured – for example, for assessing labour productivity, one would look at the ratio that represents the quantity of labour relative to the quantity of output. Labour productivity is a partial measure of productivity, also known as partial factor productivity ("PFP"). In contrast, a TFP measure would attempt to cover all types of inputs relative to all types of outputs.[11] The distinction between the TFP measure and the PFP measures therefore lies in the number of inputs analyzed – single factor productivity measures (or PFPs) relate output to a single input, whereas TFP considers output relative to all inputs. PFP measures can be misleading if considered in isolation.

Figure 2. Generalized concept of a TFP growth rate

$$\text{TFP growth rate} = \frac{\%\,\Delta\text{ weighted sum of the quantities of all outputs}}{\%\,\Delta\text{ weighted sum of the quantities of all inputs}}$$

An industry TFP study measures the changes in overall productivity for the firm and its peers over a specified time period – it is not a benchmarking study, as it does not focus on efficiency levels. In addition, an industry TFP study by definition will not focus on the regulated firm, but rather the industry as a whole. An industry TFP study is backward looking – reporting

[11] OECD. *Measuring Productivity: Measurement of aggregate and industry-level productivity growth.* 2001.

historical growth rates; the industry's long-term TFP growth rate over the study period timeframe is the primary result or finding of the study.[12]

3.2 Overview of TFP methods

The following section is an overview of the various methods of performing a TFP study. TFP methods can be broadly categorized into deterministic methodologies, which "calculate" TFP, and econometric methodologies, which "estimate" TFP. Figure 3 below gives an overview of some of the methods LEI considered; for more detail see Appendix B Section 9.1.1. LEI chose to use a TFP index method, as discussed further below.

Figure 3. Empirical techniques for estimating TFP

	Non-Frontier technique	Frontier techniques	
Parameters	Index Method	Data Envelopment Analysis ("DEA")	Stochastic Frontier Analysis ("SFA")
Description	Index number measures the ratio of all outputs (weighted by revenue shares) to all inputs (weighted by cost shares)	Linear programming technique which identifies best practice within a sample by fitting a frontier over the top of the data points and measures relative inefficiencies	Same as DEA but following econometric methods to estimate the efficiency frontier
Data needs	Quantity and price data on inputs and outputs for 2 or more firms	Quantity data on inputs and outputs for a sample of firms; price data required to get information on allocative efficiency	Quantity data on inputs and outputs for a sample of firms; price data required to get information on allocative efficiency
Advantages	Relatively simple and robust technique. Can incorporate many inputs and outputs with few observations	Can decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Can easily handle multiple outputs	Can decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Accounts for "data noise" (data errors, omitted variables, etc.) and allows for the use of standard statistic tests
Drawbacks	Does not allow for identification of various factors of TFP change such as technical efficiency, scale efficiency, etc.	Requires a large dataset. Sensitive to the way outputs and inputs specified. Can be difficult to explain in a regulatory setting	Requires large sample size for robust estimates. Requires specification of production or cost function. Can be difficult to explain in a regulatory setting

[12] It is preferable to have 10 or more years of growth rate figures; see Section 3.3 for discussion of the appropriate length of TFP study.

Source: Coelli et al. "A Primer on Efficiency Measurement for Utilities and Transport Regulators." World Bank Institute. February 2003

TFP index methods are deterministic and do not measure performance relative to an efficient frontier;[13] they measure the ratio of all outputs to all inputs, where input and output indexes are constructed using both quantities and prices of outputs and inputs. Traditionally, TFP indexing can be used to compare rates of change of productivity but not absolute levels (although more complicated multilateral index methods do also allow levels comparisons). The benefits of TFP indexing are that it is a relatively simple, easy to communicate, and robust technique that requires significantly fewer observations than the other measuring techniques, and thus it is often used for regulatory proceedings. TFP indexing is also more transparent when dealing with outliers, unlike DEA and econometric techniques. It is important to note that the TFP index method, because it is a numerical technique as opposed to a statistical technique, does not give a forecast error measure. Therefore, interpreting differences in index values requires qualitative considerations. Finally, LEI notes that the OEB and other regulators are familiar with the index approach,[14] and in the RRFE proceedings the Board stated its preference to continue to rely on productivity factors that were determined using the index-based approach.[15]

3.2.1 Selecting an indexing technique

The TFP index methodology requires selection of an indexing technique in order to calculate TFP growth rates. To determine which indexing technique was best suited for TFP calculations, LEI considered Diewert and Nakamura's 2005 review of the four most popular alternate index number formulations: Laspeyres index, Paasche index, Fisher Ideal index, and Törnqvist index (see Appendix B Section 9.1.1 for description of each index). [16] Diewert and Nakamura used the 'axiomatic' approach to the selection of an appropriate index formulation which specifies a number of desirable properties an index formulation should possess: constant quantities test,

[13] Deterministic methodologies "calculate" TFP values, as opposed to econometric methodologies which "estimate" TFP values. Non-frontier methods assume production is always efficient in their use of existing technology, and equates potential level of production at each moment in time. Non-frontier methods do not provide separate estimates of technical change and efficiency change. Further discussion regarding methods of measuring productivity can be found in Section 9.1.1.

[14] The TFP Index method has also been used in previous industry productivity studies before the OEB, and is a preferred method among practitioners for I-X regimes.

[15] OEB. *Rate Setting Parameters and Benchmarking under the Renewed Regulatory Framework for Ontario's Electricity Distributors*. Issued November 21, 2013, corrected December 4, 2013.

[16] Diewert and Nakamura. *Concepts and Measures of Productivity: An Introduction*. 2005.

constant basket test, proportional increase in outputs test, and time reversal test. Only the Fisher Ideal index satisfied all four criteria that an index number method needs to meet.[17]

Figure 4. Fisher Ideal index

$$\text{Fisher Ideal Index} = \sqrt{(\text{Laspeyres Index}) * (\text{Paasche Index})}$$

The Chained Fisher Ideal index is a geometric mean of the Laspeyres and the Paasche indices (Figure 4).[18] The Fisher Ideal index overcomes the classic 'index number problem' suffered by the Laspeyres and Paasche indices, where as one moves further away from the set of prices used, the representative quality of the index decreases (since prices change over time). The Chained Fisher Ideal index overcomes the "index number problem" as follows: instead of using one base observation for the whole period, it calculates the Fisher Ideal index for each period using the previous period's observation as the base, linking these different calculations together to form an index number series which uses the most representative weights possible for each observation.

Based on the mathematical properties and needs of TFP calculations, the Chained Fisher Ideal index ranked highest and therefore is theoretically superior to all other index methods. For this reason, LEI determined that the Chained Fisher Ideal index was most appropriate for the purposes of this study.

3.2.2 Measuring TFP growth rates

The key finding of an industry TFP study is a numerical estimate of the TFP growth rate over the study period timeframe. LEI employed two methods of measuring TFP growth rates. The first method, referred to as the 'average growth' method, calculates the year-on-year changes in the TFP Index and then takes the average of the resulting growth rates over the course of the study period.[19] As further outlined in Figure 5, a mathematical equivalent can be calculated by (i) taking the natural logarithm of the ratio of the last TFP index value divided by the first TFP index value, and (ii) then dividing the resulting value by the number of annual year-on-year observations between the start and end year.[20]

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[17] It should be noted that these four index formulations generally produce very similar results.

[18] Indexes are chained by comparing data for each year to the data from the year immediately preceding it (with the exception of the base year). This method provides a more accurate portrayal of year over year growth.

[19] Economic Insights. *Total Factor Productivity Index Specification Issues.* December 7, 2009.

[20] The number of annual changes can be calculated as the number of years for which data is collected as part of the TFP study period minus one. In our example, a study period of 2002-2012 has 11 years of data and (11 - 1 = 10) annual changes over that period.

5 Data for TFP study

Ideally, a hydroelectric industry TFP study would include a large set of peers that are similar in terms of location, capacity, and asset allocation. For the purpose of this study, the peers should include medium to large hydroelectric generators. LEI focused its data research on the United States and Canada due primarily to data availability. As outlined below, LEI considered a total of 28 hydroelectric peers across North America, including 22 in the US and 6 in Canada (including OPG). However, issues with data availability meant that 11 of these peers could not be included in the final industry peer group. Of particular note is that with the exception of OPG, no other Canadian firm could be included in the study. In the US, all major utilities are required to submit comprehensive financial and operating reports to the Federal Energy Regulatory Commission ("FERC") under FERC Form 1 ("FF1"), which is then made publicly available.[37] In contrast, no such data bank exists in Canada, and therefore the financial data required for the TFP study from Canadian peers could not be attained either through public resources or directly from the individual utilities. Still, LEI believes that a set of 16 US peers and OPG is sufficient for developing a robust TFP trend.[38]

5.1 Peer selection

5.1.1 Peer selection criteria

When selecting peers in order to construct an industry group, LEI used a multi-dimensional criteria set, which focused on comparability across peer hydroelectric operations, while keeping in mind issues related to data availability. As a general rule, LEI looked for firms that have a hydroelectric fleet with a total capacity of between 500-1,000 MW (medium size) or more than 1,000 MW (large size). Additionally, a peer needed to have more than one plant, and ideally the average age of a peer's hydro fleet would be around the average age for OPG's prescribed

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[37] FERC Form 1 is a regulatory requirement for Major electric utilities, designed to collect financial and operational information on utilities subject to FERC jurisdiction. Major utilities are defined as: having "one million megawatt hours or more; 100 megawatt hours of annual sales for resale; 500 megawatt hours of annual power exchange delivered; or 500 megawatt hours of annual wheeling for others (deliveries plus losses)." FERC Form 1 filings can be found here: <http://www.ferc.gov/docs-filing/forms/form-1/data.asp>

[38] LEI notes that there is OEB precedent to rely on US data when necessary. See for example Pacific Economic Group report: "Price Cap Index Design for Ontario's Natural Gas Utilities" (March 2007), which was undertaken under OEB directive. This study used US TFP results to establish TFP growth targets for two Canadian gas utilities (Enbridge Gas Distribution Inc. and Union Gas Limited). Report filed under OEB case number EB-2006-0209, available online at: <http://www.ontarioenergyboard.ca/documents/cases/EB-2006-0209/TFP_study_20070330.pdf>

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hydro fleet. Practical considerations relating to the availability of reliable data over the entire timeframe of the study also played an important part in peer selection.[39]

In addition to meeting the above criteria, peers needed to have data available on the hydroelectric portion of their operations, in order to ensure consistency of data. Inputs and outputs, and therefore productivity, would be completely different for thermal generation, for example. For peers which exclusively operated hydro facilities, this was straightforward. However, a number of peers were excluded from the study because there was no division in reported O&M data between the hydro and non-hydro components of their operations. Peers needed to have annual data on O&M (measured in dollars) and net generation (measured in MWh), for the 2002 through to 2012 timeframe. Revenue data was also collected when available, but was estimated when necessary (see Section 5.3 for more detail). The data and peer selection stage of the study provided LEI with plant-level hydro-specific data on annual generation (MWh), capacity (MW), and O&M (dollars), as well as revenues for developing the capital input share.

As discussed in Section 3.3, an eleven year timeframe was chosen for the study because it is long enough to smooth out anomalies associated with one off circumstances, but not too long that it relies too heavily on "stale" data or periods when data is not available. The start year of 2002 was chosen because it was the first year that full datasets could be constructed across the peer group.[40] As well, the opening of the Ontario competitive market occurred in 2002 which impacted the business environment for OPG; similarly, market restructurings were occurring across parts of the US in the late 1990s and early 2000s. The end year, 2012, was chosen because this represented the latest available information while LEI was gathering data for this study in the first quarter of 2014. Considering issues related to data availability and length requirements of a TFP study, LEI determined a study period timeframe of 2002 to 2012 was optimal.

5.1.2 Final peer group

Consistent with above criteria, LEI considered a total of 28 industry peers in North America, including 22 in the United States and 6 in Canada. These consisted of OPG, 14 private US companies that filed FERC Form 1, 2 US municipal utilities, 2 US federal power authorities, 4 US federal power administrations, and five various other Canadian companies.

However, primarily due to lack of certain necessary data, eleven peers could not be included (see more detailed discussions in Sections 5.2.3 and 5.2.4 below). The final peer group selected,

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[39] Note that LEI did not consider the ownership structure of the firm, the regulatory regime under which the firm operated, or the type of energy market in which the firm operated (e.g. bilateral energy versus regional transmission organization ("RTO") administered energy market, energy-only versus energy & capacity).

[40] Most peers did not have full datasets available before 2002, including OPG, with revenue data only available starting mid-2002 after market opening.

remove annual transmission related costs, which were not available in the annual reports but were directly provided by WAPA. However, an abnormal hydrology cycle over the course of the study period (2002-2012) was observed - WAPA's annual average hydroelectric generation was below historical average levels for many of the years in the study period and then significantly higher in last few years. Annual generation over the 2002-2012 study period can be seen in Figure 21.[55] The abnormal generation fluctuations and the size of WAPA's hydroelectric facilities were large enough to potentially skew the final TFP results. For this reason, LEI decided that WAPA should not be included in the final study.

SEPA is the only federal company that was included in the final peer group. Data for net generation, revenue, and O&M were all available in SEPA's own annual reports.[56] Unlike the other federal companies, SEPA does not own its own transmission facilities, and therefore O&M figures listed in its annual reports did not need to be corrected. Revenue figures had to be adjusted to take into account sales of "Purchased Power", which is essentially power sold by SEPA but generated by other operators.[57] This information, provided directly to LEI by SEPA, was subtracted from total revenue to calculate revenue related to the sale of SEPA's hydro power.

Municipal companies, LADWP and NYPA, were not included because their generating facilities were not entirely hydro, and neither provided hydro specific O&M figures. For LADWP, hydro was around 25% of total capacity in 2012. For NYPA, 2012 capacity was about 73% hydro, and data only extended back to 2007.[58] Given that hydro-specific O&M data could not be gathered, these companies could not be included in the TFP study.

Seattle is the only municipal power company that was included in the peer group. Data for net generation and O&M was compiled from information found within Seattle's own annual reports.[59] Seattle's generation facilities are entirely hydroelectric, and therefore generation and O&M data was already in the form necessary for the TFP study. Revenue figures for Seattle had to be estimated, as outlined in Section 5.3.

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[55] Based on information obtained from WAPA's 2002-2012 annual report.

[56] SEPA annual reports from 2007-2012 can be accessed here: <http://energy.gov/sepa/listings/annual-reports> Hard copy annual reports from 2002-2006 were provided to LEI directly by SEPA.

[57] Based on direct conversations with SEPA, information contained in annual reports, and information on company website.

[58] These amounts were obtained from LADWP and NYPA annual reports. LADWP annual reports can be found here: <https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-financialinformation?_adf.ctrl-state=1aardt9i2g_4&_afrLoop=419000985723718> and NYPA annual reports can be found here: <http://www.nypa.gov/financial/>

[59] Seattle annual reports can be found here: <http://www.seattle.gov/light/pubs/annualrpts.asp>

5.2.4 Canadian peers

In addition to the twenty two US peers above, LEI also considered five Canadian peers: Hydro Quebec, BC Hydro, Newfoundland & Labrador Hydro, Manitoba Hydro, and NB Power. To collect the necessary data, LEI reviewed Canadian databases such as StatsCan and NERC, company annual reports, regulatory filings where available, and other publicly available information for all five companies. While LEI was able to collect most of the operational data, all five companies lacked sufficient publicly-available data related to the appropriate hydro-specific O&M expenses. LEI made repeated information requests to all five companies regarding the appropriate hydro specific O&M costs, but was unable to obtain the information. Therefore, due to lack of necessary data for the TFP study, Canadian peers were ultimately excluded from the final peer list.

5.3 Revenue data estimation

As is discussed in Section 4.2.2, revenues (less O&M costs) are used to estimate capital input shares, which are in turn used to determine appropriate weights (α and $(1-\alpha)$) assigned to the two inputs (Capital and O&M). For all peers with the exception of SEPA, LEI had to perform revenue estimations in some form, because revenue data exclusively from the operation of hydroelectric operations was not obtainable directly from the primary source data.

Revenues for all the FF1 peers were estimated using reported production data and reported wholesale energy prices, because revenues are not directly reported in FF1. Monthly production data came from the EIA-923 dataset, and LEI used historical monthly ISO zone prices for peers operating within ISO market, or monthly bilateral prices for those in non-ISO markets, based on nearest power price hub traded on ICE.[60] This same process was carried out to estimate Seattle's revenue for the same reason.

For OPG, revenue data from January 2002 to April 2002 was not available because markets were not yet open; therefore, LEI had to estimate revenues by multiplying net generation for the missing months by the average of 2003-2012 HOEP prices for corresponding months. All other revenue data from April 2002 onwards was provided directly by OPG.[61]

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[60] For peers in SERC, posted bilateral prices were utilized. Certain hubs in the Pacific Northwest are not consistently traded, so LEI extrapolated to nearby hubs which were more liquid. Dominion joined PJM in 2005, so ISO prices are not available before then; LEI extrapolated based on VACAR zone price.

[61] Revenue provided by OPG solely represents energy market sales of hydroelectric generation, based on actual settlement with the IESO. It does not reflect any variance accounts, regulatory rate true ups, or any other payments such as Surplus Baseload Generation or Hydroelectric Incentive Mechanism.

9 Appendix B: Lessons learned and challenges through review of economic literature on productivity studies

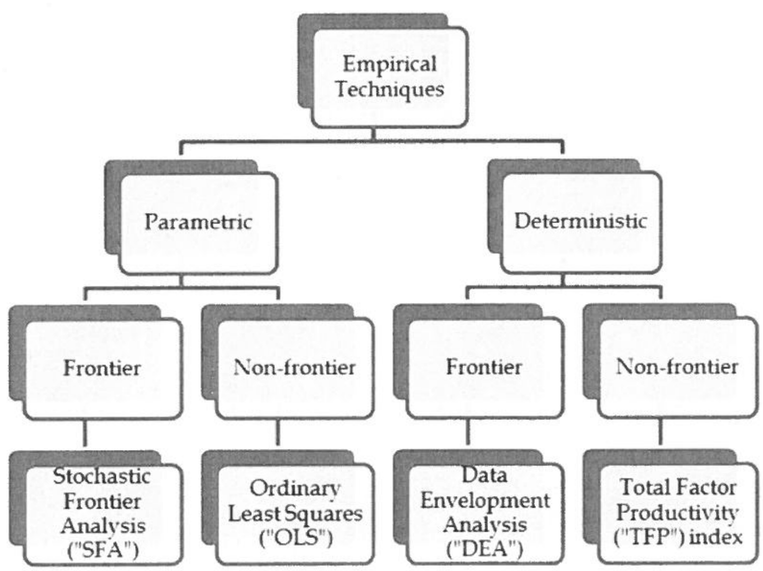
As part of the research phase of this study, LEI reviewed a number of previous studies that analyzed productivity of generation, distribution, transmission sectors, or electricity sector as a whole. For each study, data used, method employed, TFP composition (inputs and outputs), and study conclusions were summarized. This section presents the key findings of the review.

9.1.1 Methods for measuring productivity

The following section is an introduction to the various methods in performing a TFP study, specifically methods seen in the review: stochastic frontier analysis ("SFA"), Data Envelopment Analysis ("DEA"), and TFP indexes. They can be broadly categorized into deterministic methodologies, which "calculate" TFP, and econometric methodologies (which are also known as parametric methods), which "estimate" TFP.

TFP study methods can also be categorized into frontier and non-frontier. Frontier methods assume that production units do not fully use existing technology. These methods are able to break productivity growth down into technical change and efficiency change; technology changes can push the frontier upwards, while efficiency changes are productivity improvement, given the same technology. On the other hand, non-frontier methods assume that production is always efficient, and equates potential level of production at each moment in time. These methods do not separately estimate technical change and efficiency change.

Figure 33. Categories of methods used in productivity studies



First introduced by Charnes et al in 1978, DEA is a linear programming technique which identifies best practice within a sample by fitting a frontier over the top of the data points; relative efficiencies are measured from less efficient firms with respect to the frontier. As seen in the review, it is a method which is more popular in academic studies of generating units, given the amount of detail it can provide, which is discussed further below. It is often used with a Malmquist index, which measures productivity change between two points in time.

Figure 34. Common Indexing Techniques

Laspeyres Index:

- *Named for French economist Etienne Laspeyres*
- *Indexation method in which all input and output values are weighted at base year prices to ensure consistent price comparisons*
- *Becomes an increasingly inappropriate methodology as the time interval and/or price variability increases*

Paasche Index:

- *Named for German economist Hermann Paasche*
- *Indexation method similar to the Laspeyres method except that all input and outputs are value at their end of period prices to ensure price consistency*
- *Also becomes increasingly inappropriate as the time interval increases and/or the price variability increases*

Fisher Index:

- *Named for American Economist Irving Fisher*
- *Attempts to minimize the inaccuracies inherent in the Paasche and Laspeyres methods of price indexation by weighting all input and output prices by the geometric mean of base year and end of period prices*
- *The geometric mean involves the square root of the product of base year and end of period prices*
- *In a TFP period scenario, a Fisher Indexation TFP calculation can also be calculated as the geometric mean of the TFP calculations resulting from Paasche and Laspeyres indexation techniques*

Törnqvist index:

- *Attributed to Finnish economist Leo Törnqvist and is commonly used in TFP studies*
- Approximates the Fisher indexation method whereby indexes are formed by each component's weighted *geometric mean, relative to a base year, in which weights are equal to the components average cost share*
- *Typically analyzed in logarithmic format*

Malmquist Index:

- *Initially introduced in: "Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers", by Douglas W. Caves, Laurits R. Christensen and W. Erwin Diewert in 1982 but named for Swedish economist Sten Malmquist*
- *Parametric method that uses techniques similar to DEA to construct an efficient frontier which changes annually, thus measuring productivity relative to the previous year*
- *Classifies efficiency into technical change and efficiency change aspects*
- *One advantage is that it does not require price or cost information so is often in used when there are data limitation*

One of the most important benefits is that the DEA is able to decompose cost efficiency into component parts, breaking down allocative and technical efficiencies. Technical efficiencies can be in turn decomposed into scale and pure technical efficiencies. This allows researchers to identify the best role models and make recommendations on improving efficiency. As well, it is not required to specify the functional form of the production relationship, and depending on the which version of DEA is used, it is often not necessary to specify prices or weights for inputs and outputs. Specifying weights is often one of the more challenging aspects of measuring productivity.[67] Finally, this method can easily deal with multiple inputs and outputs.

In terms of weaknesses, DEA is particularly sensitive to error in measurement error for frontier firms, since DEA uses these firms to derive efficiency. DEA also requires a large dataset, where a rough rule of thumb is that the number of observations needs to be at least three times the sum of the number of outputs and inputs to get worthwhile results. Finally, DEA has not typically been used to determine X-factors in regulatory proceedings, which can be related to them being difficult to explain, being regarded as a 'black box', and poor experiences with DEA by the regulators in the early years.

TFP index methods measure the ratio of all outputs to inputs, where input and output indexes are constructed using both quantities and prices of outputs and inputs. Traditionally, it can be used to compare rates of change of productivity but not absolute levels, though more recent developments have overcome this shortcoming. Benefits are that it is a relatively simple and robust technique, and thus it is often used for regulatory proceedings. As well, index number methods can incorporate many inputs and outputs with few observations. However, it requires values for all outputs and inputs. As well, it is not able to break down efficiencies into its component parts, such as scale efficiency or technical efficiency.

SFA is an econometric method which recognizes that some of the difference between a firm's actual costs and the line of best fit are due to random events rather than inefficiency. Like DEA, SFA is also able to break down efficiencies into its component parts, such as scale efficiency or technical efficiency. Finally, it is able to separate the error term in the stochastic production function into two elements - genuine inefficiency and random fluctuations.

In terms of disadvantages, SFA is an econometric method, which is generally more complex, difficult to communicate, and require significant data. They are therefore not typically used as frequently by experts performing productivity studies for ratemaking or other regulatory purposes. Rather, they are more often used in academic studies.[68] Furthermore, they require specification of production or cost function, and although they recognize randomness in the line of best fit, if there are in fact no measurement errors in the sample, some inefficiency would be regarded as noise.

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[67] The cost efficiency version of DEA requires specification of output and input weights in the DEA data set.

[68] OECD. *Measuring Productivity: Measurement of aggregate and industry-level productivity growth.* 2001.

9.1.2 Selecting the index TFP method

In order to choose the optimal TFP method, LEI reviewed eighteen TFP studies on electricity generation companies and distribution utilities, and has summarized the lessons learned in this section. Four different methodologies for measuring productivity were used in the studies reviewed which cover the most common methodologies. In order to summarize the studies reviewed, LEI aggregated information from all 13 generator academic studies, 1 government consultation and 4 regulatory productivity studies.[69] Many methods were reviewed for measuring productivity, but TFP index methods are most popular for regulatory purposes; although DEA is widely used for academic generation studies, its advantages are not useful in regulatory proceedings.

It is clear that DEA and TFP index methods are the most common in the utility industry. It is also clear that academic studies favour DEA. Multiple academic studies highlighted DEA's ability to break down inefficiencies and offer more detailed analysis, which allowed researchers to identify role models and make recommendations on improving efficiency. This is also an advantage for using SFA. However, these advantages are not particularly relevant for regulatory purposes, and the breakdown of efficiency into technical and allocative is not important for setting an X-factor. From this perspective, no method has a clear advantage in terms of results, which may explain why the DEA method was not seen in our selected regulatory studies.

It is important to note as well that both DEA and SFA are generally complex and difficult to communicate conceptually. The issue of complexity is particularly true in the case of econometric (and semiparametric) methods such as SFA and SPSC. These more complex methods are more often used in academic studies for their various benefits discussed above. However, because they can be difficult to explain in layman terms and are considered a 'black box', DEA, SFA and SPSC methods are not often used in government consultations and regulatory studies. Index methods on the other hand are easier to communicate because people can more easily understand the concept of taking weighted averages of output and input quantities, which is an advantage for regulators. This is one of the explanations for the popularity of index methods in regulatory work.

Data wise, it is also important to note that DEA is very observation intensive. For sensible results using DEA, with a reasonable number of outputs and inputs, one needs many observations, which may prove to be an issue within OPG's peer group. Index number methods, on the other hand, can incorporate many outputs and inputs with only a few observations. Finally, index number methods are also somewhat less sensitive to outlier observations and data errors, or at least the effects are more immediately obvious with index number methods.

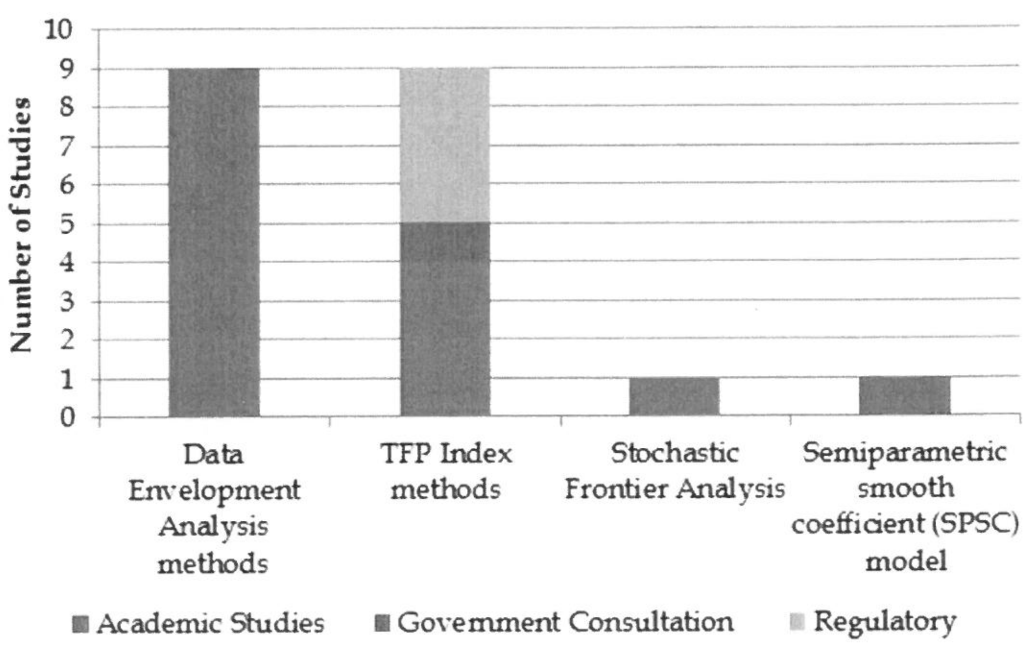
[69] Note that some studies used multiple methods.

To summarize, the indexing method is less complex, easier to communicate, and requires significantly less data than the other measuring techniques. While DEA and TFP methods are both commonly used for the electricity industry, DEA is less practical from a regulatory perspective, given its primary advantage is limited in value for setting an X-factor, it requires more data, and it is difficult to communicate. The indexing method, due to its transparency and relative simplicity, is most often the method of choice for productivity studies performed for regulatory purposes. Furthermore, in Ontario, the OEB has used the index methods for distributors. For these reasons, LEI believes the Index method is the optimal choice for measuring TFP in this study.

9.1.3 Selecting a TFP method: Review of previous studies

In order to choose the optimal TFP method, LEI reviewed eighteen TFP studies on electricity generation companies and distribution utilities, and has summarized key lessons learned in this section (for more detail see Section 9.1.2). TFP index methods were most popular for regulatory purposes, while DEA was widely used for academic generation studies but less so for regulatory proceedings.

Figure 35. Productivity study methodologies reviewed



While DEA and TFP methods are both commonly used for the electricity industry, DEA is less practical from a regulatory perspective, given its primary advantage is limited in value for setting an X-factor, it requires more data, and it is difficult to communicate. The indexing method, due to its transparency and relative simplicity, is most often the method of choice for productivity studies performed for regulatory purposes. Furthermore, in Ontario, the OEB has used the index methods for incentive regulation of distributors. For these reasons, LEI believes the Index method is the optimal choice for measuring TFP in this study.

9.1.3.1 Outputs used in TFP studies

As part of the review of 18 other productivity studies, LEI also looked at what outputs were commonly used. Despite the differences between the studies as far as methods and subject matter, there were many similarities in what was used as outputs. LEI has aggregated the parameters used by the studies related to generation, leaving out any transmission and distribution companies, as they have completely different parameters. This is summarized in Figure 36 and Figure 37 below. The most common output is energy generation in MWh, as that is what is being produced by every power plant. LEI also notes that generation data is readily available and can be consistently measured across a peer group. In two fossil fuel studies, pollutants were captured as a negative output; however, this will not be applicable to hydroelectric plants.

Figure 36. Outputs used in generation productivity studies

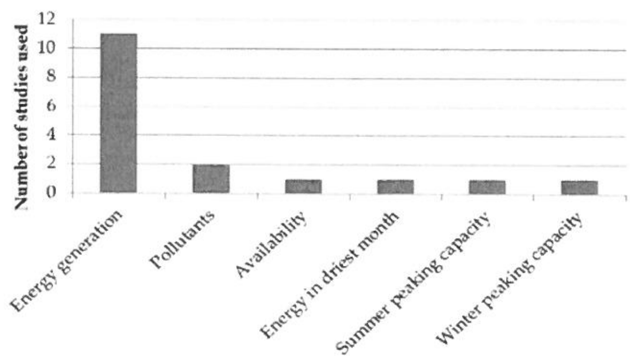


Figure 37. Example of outputs used in generation productivity studies

Outputs	Examples
Power Produced	• Generation (MWh) • Output in specific periods (e.g., to support resource adequacy)
Ancillary Services	• Reactive support/voltage control • Automatic Generation Control • Black start • Reliability must-run
Reliability	• Availability • Forced outage rates
Other Services	• Sale of ancillary services • Water management • Added flexibility to system