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Total Factor Productivity (TFP) Studies in the Electricity Sector: Emerging Issues and Recommendations

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Brittany Tarufelli, PhD
Economist, PNNL

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Presentation Overview

- Overview of the X Factor
- Common Measurement Approaches for TFP
- Key Challenges for TFP Measurement in the Electricity Sector
- Output Measurement Approaches
- Input Measurement Approaches
- Emerging Recommendations: Eversource
- Emerging Recommendations: National Grid

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X Factor

Price or revenue cap regulation provides strong incentives for cost reduction by specifying the rate at which inflation-adjusted prices or revenues must decline

- The X factor specifies the rate at which inflation-adjusted prices or revenues must decline
- When benchmarked to the rest of the economy, the X factor is equal to:

$$X = [\dot{T} - \dot{T^E}] + [\dot{W^E} - \dot{W}]$$

- The X-factor sums the difference in TFP growth rates in the electric industry and the rest of the economy $[\dot{T} - \dot{T^E}]$ (TFP differential) and the difference in input price growth rates between the rest of the economy and the electric industry $[\dot{W^E} - \dot{W}]$ (input price differential)

Common Measurement Approaches

- Allowing for an acceptable rise in price or revenue in performance-based regulation requires estimating TFP
- TFP is simply the difference in growth rates between a company's physical outputs and physical inputs

- Common Approaches to Determine TFP:

	Non-Frontier	Frontier
Non-Parametric	Index Number Methods	Data Envelopment Analysis
Parametric	Ordinary Least Squares and Other Econometric Methods	Stochastic Frontier Methods

Index Number Methods

- Index number methods combine changes in diverse outputs and inputs into measures of change in total outputs and total inputs
- A common approach: Törnqvist index:

$$\underbrace{lnA_{it} - lnA_{it-1}}_{Growth\ in\ TFP} = \underbrace{ln\frac{Q_{it}}{Q_{it-1}}}_{Growth\ in\ Output} \underbrace{- \underbrace{\left(\frac{s_{it}^{L} + s_{it-1}^{L}}{2}\right)}_{Labor\ Share} ln\frac{L_{it}}{L_{it-1}} - \underbrace{\left(\frac{s_{it}^{K} + s_{it-1}^{K}}{2}\right)}_{Capital\ Share} ln\frac{K_{it}}{K_{it-1}}}_{Growth\ in\ Input}$$

- Requires information on output, Q, inputs labor, L, and capital, K, and the relative shares of wages or capital rents included in output prices, s^L or s^K, for firm i at times t and $t-1$

Index number methodologies essentially take a weighted average of the changes in outputs and inputs.

Key Challenges for TFP Measurement in the Electricity Sector

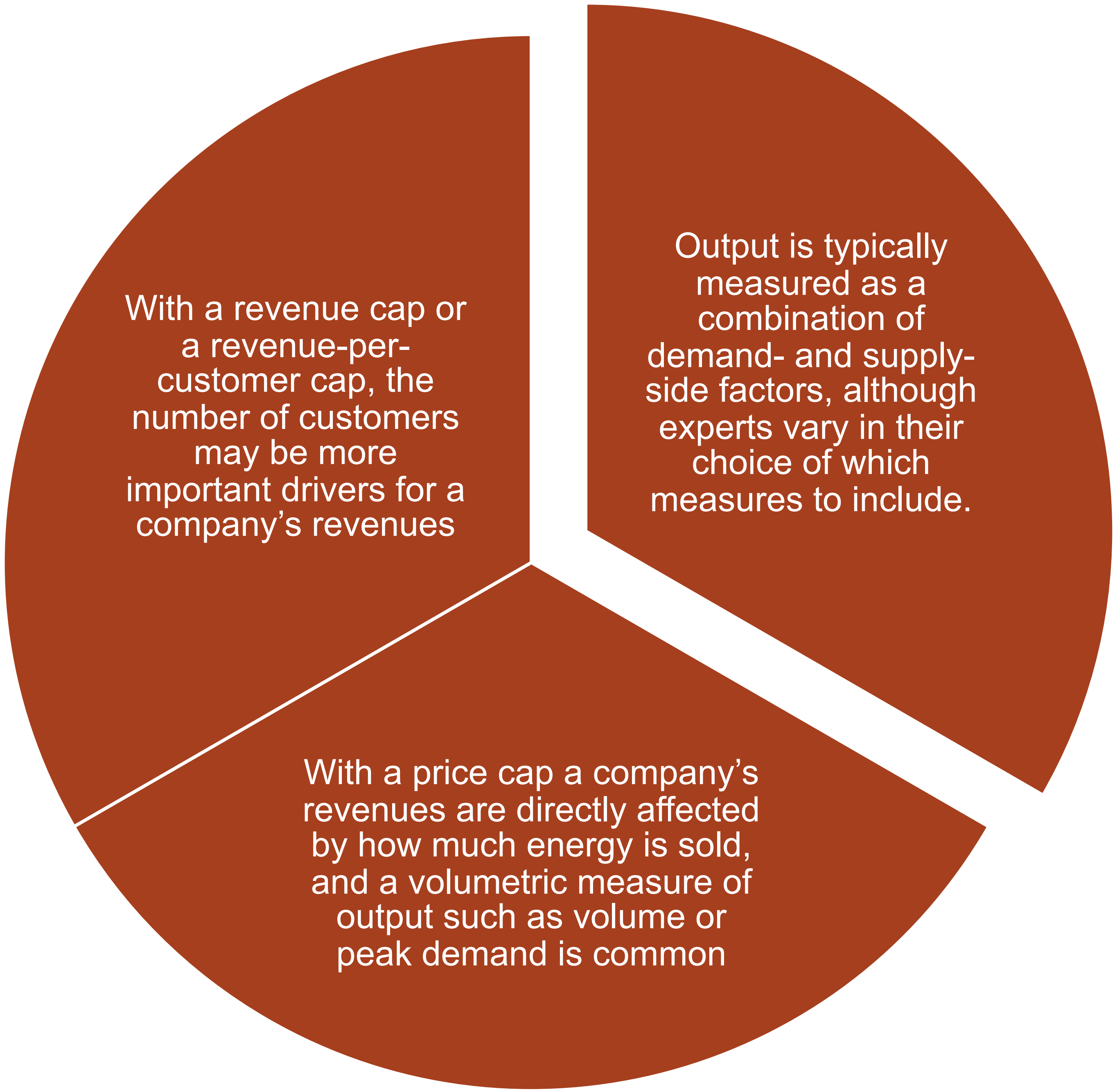
Key challenges in TFP measurement include the measurement of output, the measurement of input—especially the concept of capital—missing or inappropriate data, and the weights used for indexes

Output Measurement Approaches

Outputs can be measured from the perspective of demand or supply:

The demand approach considers output to be the amount and value of energy (throughput) provided by distributors to their consumers	• A distributor's volume of sales may represent energy throughput and total revenue represents its value
The supply approach instead considers output as a measure of the availability of infrastructure and the condition of that infrastructure	• Distributors must also provide and maintain infrastructure for delivering electricity to consumers (and this is not costless) • Reliability, quality, and quantity of electricity supplied as well as coverage and capacity of the system

Output Measurement Approaches



Input Measurement Approaches

Input indexes are used to capture growth in input quantities and growth in input prices, as both components make up the growth in company costs

Input indexes are typically comprised of multiple inputs, with distribution systems typically including two broad categories: operations and maintenance expenditure and capital expenditure	In North America, operations and maintenance is often separated into labor, materials, and services	The weights of input indexes are determined by the relative cost share of each input to the total cost of all inputs, with capital subindexes typically being allocated the heaviest weights as distribution systems are capital intensive

Labor, Materials and Services

Quantity can be measured directly when data permits.

For example, labor quantity can be measured with the number of full-time employees, although labor input data is increasingly difficult to obtain due to contracted labor services

Quantity can be measured indirectly by deflating the value of relevant costs.

For example, labor costs (measured by salary and wage expenses) can be deflated by relevant labor price indexes (measured by a salary and wage price index) to obtain implicit quantity measures.

Capital Measurement Approaches

The capital quantity index often measures the flow of services from the acquired capital assets

- Capital quantity can be measured directly.
  - For example, with a measure of line length or transformer capacity.

- Capital quantity can be measured indirectly with the deflated asset value method.
  - For example, capital quantity index is constructed by deflating data on the value of assets—a utility plant value is deflated using a construction cost index

Capital price index measures the prices that would be earned in a competitive market for the rental of capital services—a price that has to be inferred as most capital is owned by the distribution company

Key Points for Capital Measurement

Capital Measurement

Total capital stock needs to be inferred from current and past additions

One method for adding up current and past additions is the perpetual inventory method

A specific model of depreciation is chosen:

One Hoss Shay

Geometric Decay

Straight Line

Annual capital costs can be measured directly by applying a constant percentage reflecting depreciation, the opportunity cost of capital and the rate of capital gains to the value of assets

(Or indirectly as revenues minus operating costs)

Preliminary Review Key Takeaways

From a preliminary review we find that the two previous TFP studies appear largely in line with best practices, but provide recommendations for consideration in future X factor studies

Some key takeaways are that study methodologies and assumptions should be transparent enough that the study could be reproduced, and sensitivity analysis of key assumptions can be undertaken to show the sensitivity of TFP to changing those key assumptions

Emerging Recommendations: Eversource Sample Parameters

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Sample Period: The selected sample period was 2001 to 2015. Although Eversource acknowledged that a longer sample period is a better indicator of future expectations, because post-2007, energy efficiency and other conservation measures created a divergence between electrical use and economic growth, this sample period was selected.	**Evaluation** Length of study is likely long enough to uncover long-run productivity trends rather than the trend of an underlying business cycle. **Benefits** Length of study is chosen to be reflective of the growth trend that is likely to occur during the PBR period. **Drawbacks** Estimating TFP trends for shorter sample lengths can be more volatile due to input price or demand fluctuations, whereas long-run trends can smooth these effects. No statistical tests were provided to evidence structural breaks occurred in long-term growth trends. **Recommendations** If it is believed that long-term growth trends are unstable, statistical tests can be used to determine if a structural break has occurred.
Selection of Peer Group: Two different samples were used: (1) a sample of 67 firms intended to represent the overall U.S. electric distribution industry (2) a sample of 17 firms intended to represent the distribution industry in the Northeast U.S.	**Evaluation** Choosing a representative sample of firms that constitutes the electric industry is a commonly used approach to determine the productivity growth for the X-factor in North America. Further, when productivity growth (rather than productivity levels) is the TFP metric, heterogeneity largely vanishes and is advisable to use the largest possible sample of firms. **Benefits** The sample selected should result in a TFP trend that represents a reasonable productivity estimate for Eversource. **Drawbacks** If there is reason to believe heterogeneity persists, a sample can be restricted to more comparable firms, so long as care is taken to account for factors that drive productivity differences across firms. However, if productivity trends are dominated by a handful of utilities, TFP may be biased. Sample should also be large enough to determine robust estimates. **Recommendations** As was done in this study, the robustness of the X-factor to sample selection parameters can be examined.

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Emerging Recommendations: Eversource

- Inflation Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Gross Domestic Product Price Index Data Source: Economy-wide TFP and input price growth are obtained from official U.S. governments sources.	**Evaluation** When a macroeconomic inflation index is used, an additional term (the input price differential) must also be estimated because if the input price trend of the economy rises more rapidly than that of the electric distribution industry, the X-factor will be larger, and this was included in this TFP analysis. **Benefits** Benchmarking the electricity industry to the rest of the economy recreates the pressures of the competitive market. **Drawbacks** None noted. **Recommendations** None noted.

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Emerging Recommendations: Eversource

- Output Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Total number of customers was the sole productivity output measure. Two reasons are cited: (1) the number of customers is a primary driver of costs for electricity distribution; and (2) the revenue cap proposed by Eversource is more comparable to a revenue per customer cap than a price cap. Customer counts were from FERC Form 1 (average number of customers). If unbundled customers were not reported, distribution customers from EIA 861 were added to total customers from the FERC form. (Additional analysis on customer count method to be completed).	**Evaluation** With a revenue or revenue per customer cap, the number of customers are important drivers for a company's costs (and revenues). However, practitioners also recommend multifactor output measures to reflect changes in output trends. **Benefits** The number of customers is an important driver for a distributor's costs (and revenues) (see Lowry, 2018; Lowry and Makos, 2018). **Drawbacks** In the literature, productivity differences among electricity distribution firms can also be driven by energy density, customer density, network density, peak demand, and the customer mix. Combining several output measures can reflect changes in output trends. Lawrence and Diewert (2004) recommend a three variable specification comprised of energy throughput, system capacity, and number of customers to incorporate important density variables that drive distributors' costs. Makholm (2018) notes that TFP studies tend to use a mix of output measures (number of customers, line miles, peak usage, kWh, etc.) to reflect changing output trends due to investment in advanced metering infrastructure or energy efficiency. **Recommendations** Although the number of customers is an important cost driver, future TFP studies could consider different combinations of output measures which incorporate important density variables that drive distributors' costs to examine the sensitivity of TFP growth to different combinations of output measures.

Emerging Recommendations: Eversource

- Labor Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Labor Index Quantity of labor is the labor cost on the direct payroll distribution booked to electricity distribution operating and maintenance expenses, found in FERC Form 1, divided by the price of labor. The price of labor is based on the BLS Employment Cost Index for utility industry wages and salaries.	**Evaluation** This approach to measure the quantity of labor is an indirect measurement approach which deflates labor costs by a relevant labor price index, which is an accepted practice in the literature. **Benefits** The benefit of this approach is it circumvents the need to obtain labor quantity data, which may be increasingly difficult to obtain and estimate due to increasing levels of contracted labor. **Drawbacks** (In process). It appears this methodology (although an accepted one) deviates from that in Makholm and Ros (2010), the NERA study cited as evidence for the acceptability of this TFP study. Because there were some issues noted with the calculation of labor in the Makholm and Ros (2010) study (see Meitzen, 2016), it would be helpful to document more clearly the deviations from that study in the calculation of labor. **Recommendations** Due to the reliance on the Makholm and Ros (2010) (NERA) study as an accepted methodology, deviations from that methodology should be clearly documented.

Emerging Recommendations: Eversource

- Materials Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Materials Index Quantity of materials is the materials cost (based on operating and maintenance expense for distribution from FERC Form 1 less direct payroll distribution), divided by the price of materials The price of materials is based on the BLS Economic Analysis Gross Domestic Product Price Index.	**Evaluation** This approach to measure the quantity of materials is an indirect measurement approach which deflates materials costs by a relevant materials price index. This is the methodology for materials from the AUC proceedings and is widely used in the literature. **Benefits** The indirect measurement approach circumvents the need to estimate materials quantity directly, as this data may be difficult to obtain from available data. **Drawbacks** Additional materials and services expenses, such as a sensible share of administrative and general expenses (exclusive of those for pension and benefits) are also included in other studies. **Recommendations** Sensitivity analyses can be performed over inclusion or exclusion of various expenses related to distribution materials.

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Emerging Recommendations: Eversource

- Capital Measurement

Method/Assumption

Capital Index

Quantity of capital is derived from a perpetual inventory equation:

$$K_t = K_{t-1} + I_t - R_t$$

Where K_t is the end-of-year capital stock, K_{t-1} is the end of year capital stock from the previous year, I_t are the quantity of capital additions during the year, and R_t the quantity of retirements during the year. To estimate the quantity of capital additions, distribution additions to plant in service from FERC Form 1 are divided by the Handy-Whitman index for distribution plant. The quantity of retirements is estimated from dividing distribution retirements from plant in service from FERC Form 1, divided by a lagged value of the Handy-Whitman index (lag of 33 years, to represent the average depreciable service life of the distribution plant).

The benchmark value of the plant is constructed as follows: because the net book value of the plant is not reported in FERC Form 1, it is estimated by taking the ratio of distribution plant in service to total electric plant in service, and applying it to net electric plant in service.

$$K_{1964} = \frac{NetElectricPlantInServ * \left(\frac{DistributionPlantinService}{TotalPlantIn\,Service}\right)}{\sum_{i=1}^{20} \frac{i * HW_{1944}}{\sum_{i=1}^{20} i}}$$

Last, once the end-of-year capital stock is computed, the flow of capital services during a year is based on the quantity of capital stock from the previous year

$$KS_t = K_{t-1}$$

The price of capital is derived from an implicit rental price equation that corresponds to the perpetual inventory equation described above:

$$PK_t = \frac{1-uz}{1-u}(r-i)\left[1-\left(\frac{1+i}{1+r}\right)^{33}\right]^{-1} HW_{t-1}$$

Where u is corporate profits tax rate, z the present value of tax depreciation on one dollar of investment in distribution plant and equipment, r is the forward-looking cost of capital, and i the forward-looking inflation rate. The number 33 represents the asset life used in the perpetual inventory equation.

Emerging Recommendations: Eversource

- Capital Measurement

Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Evaluation The depreciation assumption should best reflect the underlying depreciation profile of the asset. In this case, both the Department and Eversource agreed that these capital assets' contribution to the Company's productivity remains relatively constant until it is retired, which is in line with the underlying depreciation profile of one-hoss-shay. The capital quantity and price indexes reflect the same depreciation assumption. The capital cost index was smoothed to reduce capital cost volatility. Assessment of method to smooth capital cost volatility (in progress) The choice of benchmark year (1964) allows for many years of plant additions to minimize measurement error **Benefits** The methods and assumptions chosen are largely in line with the literature, with the exception of the choice to use the net plant value rather than the gross plant value, however TFP studies do not always align with the literature in their choice of gross or net plant value for the benchmark value. **Drawbacks** The one-hoss-shay method is more sensitive to the useful life of the asset than the geometric decay assumption because the value of the capital stock is entirely determined by the useful life. With this TFP study, the benchmark value of the plant was constructed from estimating the net book value of the plant rather than the gross plant value, which can create a downward bias in the TFP trend if net plant value underestimates capital quantity. In the literature, the gross plant value is appropriate for the one-hoss-shay depreciation assumption and net plant value for the geometric decay depreciation assumption (see Diewert and Lawrence, 2000; Lowry and Makos 2018). **Recommendations** Sensitivity analyses can be performed to determine the impacts to TFP from using gross or net plant value. Sensitivity analyses can be performed to determine the impacts to TFP from smoothing the capital cost volatility (pending). Sensitivity analyses can also be performed to different depreciation assumptions if the underlying depreciation profile of the asset is in question.

Emerging Recommendations: Eversource

- Supplemental Capital

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
The $400 million grid modernization base commitment investment (representing an implicit stretch factor of 1.08%) was removed from the X-factor and a capital cost tracker was used instead.	**Evaluation** Capital trackers are increasingly common as it is challenging to recover capital expenditures, however, capital trackers can distort incentives for cost containment. **Benefits** Capital trackers are administered in a manner similar to cost-of-service regulation. **Drawbacks** Capital trackers can weaken incentives for capex cost containment. Further capital trackers can discourage a utility from optimizing its resources across all inputs (for example, avoiding inefficient substitution between labor and capital). **Recommendations** Consider the effective X-factor ($X' = X - K$), as supplemental capital can lead to overall increases in prices or revenues when these factors add on to the PBR plan. Consider also designing superior incentives for supplemental capital plans (Meitzen et al., 2017). See for example, the K-bar capital mechanism adopted in the 2018 – 2022 Performance-Based Regulation Plans for Alberta Electric and gas Distribution Utilities (Errata to Decision 20414-D01-2016).

Emerging Recommendations: Eversource

- Weighting Methods

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Quantity Index of Total Input The quantity index of total input is constructed for each firm using the multilateral Törnqvist indexing procedure with the form: $\ln(X_{i,t}) = \frac{sk_{it} + \overline{sk}}{2}(lnKS_{it} - \overline{lnKS}) + \frac{sl_{it} + \overline{sl}}{2}(lnL_{it} - \overline{lnL}) + \frac{sm_{it} + \overline{sm}}{2}(lnM_{it} - \overline{lnM})$ Where sk denotes the cost share of capital, sl the cost share of labor, and sm the cost share of materials, and a bar above the variable represents the average value over all firms and all years. The Price Index of Total Input is computed similarly for the price of capital, materials, and labor: $\ln(X_{i,t}) = \frac{sk_{it} + \overline{sk}}{2}(lnPK_{it} - \overline{lnPK}) + \frac{sl_{it} + \overline{sl}}{2}(lnPL_{it} - \overline{lnPL}) + \frac{sm_{it} + \overline{sm}}{2}(lnPM_{it} - \overline{lnPM})$	**Evaluation** The multilateral Törnqvist index is a common methodology where weights are computed relative to the average firm. **Benefits** The multilateral Törnqvist index allows for comparisons that are bilateral and transitive, and it is widely used in the literature. **Drawbacks** (In process) The derivation of the cost share of capital, labor, and materials was not explicitly discussed. **Recommendations** Methodologies for determining revenue or cost shares should be clearly documented and make sense based on the data used to determine the shares.

Emerging Recommendations: Eversource

- Weighting Methods

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
To determine industry rates of growth, each firm was weighted by its relative number of customers: $$s_i = \frac{CUST_{it}}{\sum_i CUST_{it}}$$ Where s_i is the weighting factor for each firm. The industry rate of total output growth is then: $$\ln {}^{Y_t}/_{Y_{t-1}} = \sum_i s_i \left({}^{CUST_{it}}/_{CUST_{i,t-1}} \right)$$ The industry rate of total input growth is: $$\ln {}^{X_t}/_{X_{t-1}} = \sum_i s_i \left({}^{X_{it}}/_{X_{i,t-1}} \right)$$ The industry rate of total input price growth is: $$\ln {}^{P_t}/_{P} = \sum_i s_i \left({}^{P_{it}}/_{P_{i,t-1}} \right)$$ The industry rate of TFP growth is: $$\ln {}^{TFP_t}/_{TFP_{t-1}} = \ln {}^{Y_t}/_{Y_{t-1}} - \ln {}^{X_t}/_{X_{t-1}}$$	**Evaluation** Indexes were weighted by the relative number of customers to provide more weight to more similar (larger) firms, which is an accepted practice in the literature. **Benefits** TFP trends are more representative of those for larger firms. **Drawbacks** Different weighting methods can result in TFP growth. **Recommendations** Sensitivity analyses on the weighting method can be performed if there are concerns that the weighting method is biasing TFP growth.

Emerging Recommendations: National Grid

- Sample Parameters

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Sample Period: The selected sample period was 2002 - 2016 This time period was chosen to balance the most recent, relevant information within a long enough period to overcome transient, short-term occurrences that could inappropriately skew the results of the TFP study.	**Evaluation** Length of study is likely long enough to uncover long-run productivity trends rather than the trend of an underlying business cycle. **Benefits** Length of study is chosen to be reflective of the growth trend that is likely to occur during the PBR period. Further, years prior to 2002 were excluded to avoid the sample including the effects of technological advancements (computerization and automation) that are now fully incorporated into the Company's operations. **Drawbacks** Estimating TFP trends for shorter sample lengths can be more volatile due to input price or demand fluctuations, whereas long-run trends can smooth these effects. No statistical tests were provided to evidence structural breaks occurred in long-term growth trends. **Recommendations** If it is believed that long-term growth trends are unstable, statistical tests can be used to determine if a structural break has occurred.
Selection of Peer Group: Two different samples were used: (1) a sample of 66 firms intended to represent the overall U.S. electric distribution industry (2) a sample of 18 firms intended to represent the distribution industry in the Northeast U.S.	**Evaluation** (Evaluation in progress, preliminary evaluation) Choosing a representative sample of firms that constitutes the electric industry is a commonly used approach to determine the productivity growth for the X-factor in North America. Further, when productivity growth (rather than productivity levels) is the TFP metric, heterogeneity largely vanishes and is advisable to use the largest sample of firms. It was noted that although the largest sample of firms was not used, the sample was of sufficient size to be representative of the industry. **Benefits** The sample selected should result in a TFP trend that represents a reasonable productivity estimate for National Grid. **Drawbacks** If there is reason to believe heterogeneity persists, a sample can be restricted to more comparable firms, so long as care is taken to account for factors that drive productivity differences across firms. However, if productivity trends are dominated by a handful of utilities, TFP may be biased. Sample should also be large enough to determine robust estimates. **Recommendations** As was done in this study, the robustness of the X-factor to sample selection parameters can be examined.

Emerging Recommendations: National Grid

- Inflation Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Gross Domestic Product Price Index GDPPI is obtained from an official U.S. governments source	**Evaluation** When a macroeconomic inflation index is used, an additional term (the input price differential) must also be estimated because if the input price trend of the economy rises more rapidly than that of the electric distribution industry, the X-factor will be larger, and this was included in this TFP analysis. **Benefits** Benchmarking the electricity industry to the rest of the economy recreates the pressures of the competitive market. **Drawbacks** None noted. **Recommendations** None noted.

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Emerging Recommendations: National Grid

- Output Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Total number of customers was the sole productivity output measure. Customer counts were from EIA 861 "Sales to Ultimate Customers" bundled and delivery customers were included. (Additional analysis on customer count method to be completed).	**Evaluation** With a revenue or revenue per customer cap, the number of customers are important drivers for a company's costs (and revenues). However, practitioners also recommend multifactor output measures to reflect changes in output trends. **Benefits** The number of customers is an important driver for a distributor's costs (and revenues) (see Lowry, 2018; Lowry and Makos, 2018). **Drawbacks** In the literature, productivity differences among electricity distribution firms can also be driven by energy density, customer density, network density, peak demand, and the customer mix. Combining several output measures can reflect changes in output trends. Lawrence and Diewert (2004) recommend a three variable specification comprised of energy throughput, system capacity, and number of customers to incorporate important density variables that drive distributors' costs. Makholm (2018) notes that TFP studies tend to use a mix of output measures (number of customers, line miles, peak usage, kWh, etc.) to reflect changing output trends due to investment in advanced metering infrastructure or energy efficiency. **Recommendations** Although the number of customers is an important cost driver, future TFP studies could consider different combinations of output measures which incorporate important density variables that drive distributors' costs to examine the sensitivity of TFP growth to different combinations of output measures.

Emerging Recommendations: National Grid

- Distribution Labor Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Distribution Labor Index Quantity of labor is the labor cost on the direct payroll distribution booked to electricity distribution operating and maintenance expenses, found in FERC Form 1, divided by the price of labor. The price of labor is based on the BLS Employment Cost Index for utility industry wages and salaries.	**Evaluation** This approach to measure the quantity of labor is an indirect measurement approach which deflates labor costs by a relevant labor price index, which is an accepted practice in the literature. **Benefits** The benefit of this approach is it circumvents the need to obtain labor quantity data, which may be increasingly difficult to obtain and estimate due to increasing levels of contracted labor. **Drawbacks** (In progress) See those mentioned for the Eversource study in Table X. **Recommendations** (Evaluation in progress).

Emerging Recommendations: National Grid

- Distribution Materials Measurement

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Distribution Materials Index Quantity of materials is the materials cost (based on operating and maintenance expense for distribution from FERC Form 1 less direct payroll distribution), divided by the price of materials The price of materials is based on the BLS Economic Analysis Gross Domestic Product Price Index. National grid also produced X-factors which omitted any plant-apportioned administrative and general expenses.	**Evaluation** This approach to measure the quantity of materials is an indirect measurement approach which deflates materials costs by a relevant materials price index. This is the methodology for materials from the AUC proceedings and is widely used in the literature. **Benefits** The indirect measurement approach circumvents the need to estimate materials quantity directly, as this data may be difficult to obtain from available data. **Drawbacks** None noted. **Recommendations** None noted.

Emerging Recommendations: National Grid

- Customer Accounts and Sales
- Administrative and General

Method/Assumption	Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Customer Accounts and Sales Labor Index Customer accounts and sales expenses were included in O&M expenses. The labor expense portions are line items in FERC Form 1, the price of labor is based on the BLS Employment Cost Index for utility industry wages and salaries, with the quantity of labor derived by dividing the cost of labor by its price.	**In Progress**
Customer Accounts and Sales Materials Index Customer accounts and sales expenses were included in O&M expenses. The materials expenses for customer accounts and sales expenses are total O&M expenses for these accounts less the direct payroll distribution for these accounts. The price of materials is based on the BLS Gross Domestic Product Price Index , with the quantity of materials derived by dividing the cost of materials by its price.	**In Progress**
Administrative and General (A&G) Labor Index Because A&G expenses are comprised of joint and common costs that pertain to activities that span distribution, transmission, and production (rather than just distribution). To assign these costs to the distribution function, the portion of joint and common A&G expenses allocated to the distribution function is determined by multiplying a firm's total A&G expenses for each year in the sample by the annual average across all firms in the sample of the percent of distribution plant relative to total plant. The labor expense portions are line items in FERC Form 1. The price of labor is based on the BLS Employment Cost Index for utility industry wages and salaries, with the quantity of labor derived by dividing the cost of labor by its price.	**In Progress**
Administrative and General (A&G) Materials Index Because A&G expenses are comprised of joint and common costs that pertain to activities that span distribution, transmission, and production (rather than just distribution). To assign these costs to the distribution function, the portion of joint and common A&G expenses allocated to the distribution function is determined by multiplying a firm's total A&G expenses for each year in the sample by the annual average across all firms in the sample of the percent of distribution plant relative to total plant. The materials expenses for A&G expenses are the total expenses for these accounts less the direct payroll distribution for these accounts. The price of materials is based on the BLS Gross Domestic Product Price Index , with the quantity of materials derived by dividing the cost of materials by its price.	**In Progress**

Emerging Recommendations: National Grid

- Capital Measurement

Method/Assumption

Capital Index

Quantity of capital is derived from a perpetual inventory equation:

$$K_t = K_{t-1} + I_t - R_t$$

Where K_t is the end-of-year capital stock, K_{t-1} is the end of year capital stock from the previous year, I_t are the quantity of capital additions during the year, and R_t the quantity of retirements during the year.

To estimate the quantity of capital additions, distribution additions to plant in service from FERC Form 1 are divided by the Handy-Whitman index for distribution plant. The quantity of retirements is estimated from dividing distribution retirements from plant in service from FERC Form 1, divided by a lagged value of the Handy-Whitman index (lag of 33 years, to represent the average depreciable service life of the distribution plant).

The benchmark value of the plant is constructed as follows: because the net book value of the plant is not reported in FERC Form 1, it is estimated by taking the ratio of distribution plant in service to total electric plant in service, and applying it to net electric plant in service.

$$K_{1964} = \frac{NetElectricPlantInServ * \left(\frac{DistributionPlantinService}{TotalPlantIn\ Service}\right)}{\sum_{i=1}^{20} \frac{i * HW_{1944}}{\sum_{i=1}^{20} i}}$$

Last, once the end-of-year capital stock is computed, the flow of capital services during a year is based on the quantity of capital stock from the previous year

$$KS_t = K_{t-1}$$

The price of capital is derived from an implicit rental price equation that corresponds to the perpetual inventory equation described above:

$$PK_t = \frac{1 - uz}{1 - u}(r - i)\left[1 - \left(\frac{1 + i}{1 + r}\right)^{33}\right]^{-1} HW_{t-1}$$

Where u is corporate profits tax rate, z the present value of tax depreciation on one dollar of investment in distribution plant and equipment, r is the forward-looking cost of capital, and i the forward-looking inflation rate. The number 33 represents the asset life used in the perpetual inventory equation.

Emerging Recommendations: National Grid

- Capital Measurement

Evaluation, Benefits, Drawbacks, and Recommendations for Method/Assumption
Evaluation The depreciation assumption should best reflect the underlying depreciation profile of the asset. With one-hoss-shay the level of services of the asset remain relatively constant until it is retired. In this case, the Department noted that this method best reflected the pattern of service flow observed in the electric distribution industry The capital quantity and price indexes reflect the same depreciation assumption. The capital cost index was smoothed to reduce capital cost volatility. Assessment of method to smooth capital cost volatility (in progress) The choice of benchmark year (1964) allows for many years of plant additions to minimize measurement error Assessment of useful life calculation (evaluation in progress) **Benefits** The methods and assumptions chosen are largely in line with the literature, with the exception of the choice to use the net plant value rather than the gross plant value, however TFP studies do not always align with the literature in their choice of gross or net plant value for the benchmark value. **Drawbacks** The one-hoss-shay method is more sensitive to the useful life of the asset than the geometric decay assumption because the value of the capital stock is entirely determined by the useful life. With this TFP study, the benchmark value of the plant was constructed from estimating the net book value of the plant rather than the gross plant value, which can create a downward bias in the TFP trend if net plant value underestimates capital quantity. In the literature, the gross plant value is appropriate for the one-hoss-shay depreciation assumption and net plant value for the geometric decay depreciation assumption (see Diewert and Lawrence, 2000; Lowry and makos 2018). **Recommendations** Sensitivity analyses can be performed to determine the impacts to TFP from using gross or net plant value. Sensitivity analyses can be performed to determine the impacts to TFP from smoothing the capital cost volatility. Sensitivity analyses can also be performed to different depreciation assumptions if the underlying depreciation profile of the asset is in question.

Conclusion and Next Steps

- In this review, we provided an overview of common methods for estimating TFP, including index number methods, approaches to measuring outputs and inputs when using index number methods, as well as a review of best practices.
- From a preliminary review we find that the two previous proposals appear largely in line with best practices, but provide recommendations for consideration in future X factor studies
  - Some key takeaways are that study methodologies and assumptions should be transparent enough that the study could be reproduced, and sensitivity analysis of key assumptions can be undertaken to show the sensitivity of TFP to changing those key assumptions
- In our next steps, we will finalize our review of the two previous proposals and provide a draft report for your review and feedback at the end of September 2022.

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Thank you

Appendix: Total Factor Productivity

- In a competitive market (with long-term profits driven to zero) a company's growth rate in output prices, $\dot{P}$, is equal to its growth rate in input prices, $\dot{W}$, minus its growth rate in TFP, $\dot{T}$:

$$\dot{\mathrm{P}} = \dot{\mathrm{W}} - \dot{\mathrm{T}}$$

- Where the company's TFP growth rate is simply the growth rate of its output quantities minus the growth rate of its input quantities.
- Strong performance incentives depend on accurately forecasting changes in input prices and TFP, or finding an appropriate benchmark
  - Benchmark Example:
- In practice, prices or revenues are indexed to macroeconomic inflation indicator (GDPPI) and reduced by the productivity offset, or X-factor

Appendix: Multifactor Output Measurement Approaches

- Some practitioners recommend combining several output measures to reflect changes in output trends.
  - Lawrence and Diewert (2004) recommend a three variable specification comprised of energy throughput, system capacity, and customers (number of connections) to incorporate both customer- and sales-density variables for measuring output for TFP analysis for Australia.
  - Makholm (2018) relates the choice of output variables to the importance of reflecting changes in output trends due to the changing nature of investments, as an increase in inputs may not necessarily lead to an increase in output (for example investments in advanced metering infrastructure aim to reduce electricity demand). A mix of output measures (number of customers, line miles, peak usage, etc.) in addition to the traditional output measure (kWh) are used to reflect these changing output trends.
- Aggregating disparate outputs into total output requires the use of index number methods, which require a weight be allocated to each output. A commonly used weight is the share of revenue for each output.
  - If there isn't an explicit price available for each output, the revenue share has to be inferred, usually from econometric data, where a common approach is to use an econometric cost function to derive cost elasticities

Appendix: Capital Quantity Measurement Approaches

- Often, a practitioner will observe the new capital (I_t) added to the capital stock (K_t) each year, but not the total capital stock at that point in time.
- The total capital stock will need to be inferred from past and current additions, accounting for the possibility that older capital may be less productive
    - ✓ In practice, it is typical for capital to be valued based on capital additions in each year of the study rather than using the gross or net plant balances in utility accounts.
  - One method for adding up capital additions (I) into capital stock (K) is the perpetual inventory method.

$$K_t = \phi_0 I_t + \phi_1 I_{t-1} + \cdots + \phi_t I_{t-T},$$

    - ✓ Where $\phi_0 = 1$ and $t - T$ is the date of the oldest surviving vintage
    - ✓ Requires determining a benchmark year, or the opening balance, at the start of the study, which is developed by using gross or net plant balances in that year
    - ✓ Requires estimation of efficiency weights (ϕ) (physical asset depreciation is equal to the reduced efficiency, or decline in value, as an asset progresses in age)

Appendix: Capital Quantity Measurement Approaches

- Because efficiency weights (ϕ) are rarely observed, relative efficiency can be estimated indirectly by assuming ϕ follows an observable pattern
  - Physical asset measures assume a “one-hoss-shay” depreciation profile
  - Depreciated asset value method has an implicit assumption of geometric or straight-line depreciation
- The specific model of depreciation chosen implies different measures for the flow of services from capital, which will lead to different measures of TFP growth

Appendix: Capital Price Measurement Approaches

- The annual cost of using capital inputs can be measured directly by applying a constant percentage reflecting depreciation, the opportunity cost of capital, and the rate of capital gains to the value of assets
- Or the annual cost of using capital inputs can be measured indirectly as the residual from the equation: revenue minus operating costs
- The direct approach to measuring capital costs requires the application of a "user cost":

$$U_t = P_t - (1 + r)^{-1} P_{t+1}$$

- Where the user cost of an asset that is t years old (U_t) is equal to its purchase price (P_t) minus the discounted end of period price one year in the future, $(1 + r)^{-1} P_{t+1}$, where the real interest rate is r. Note that in practice, other factors such as taxes and incentives will affect capital costs, requiring user costs that take these factors into account

Appendix: Depreciation Assumption: One Hoss Shay

- With the "one-hoss-shay" depreciation assumption, the rental price for a new asset is

$$U_0 = P_0 r(1+r)^{-1}[1-(1+r)^{-N}]^{-1}$$

  - ✓ Where U_0 is the user cost, P_0 is the asset price at time zero, the real interest rate is r, and the useful life of the asset is N

- The efficiency of an asset (ϕ) over the service life of the asset ($t = 0, 1, 2, \ldots, T$) is assumed to be fully efficient (i.e., equal to one) until the asset falls apart when the service life ends
- This efficiency pattern is completely determined by the service life of the asset

$$\phi_0 = \phi_1 = \ldots = \phi_{T-1} = 1, \phi_{T+t} = 0$$

- With "one-hoss-shay" as the depreciation assumption, the gross capital stock model is appropriate for aggregating vintages of capital stock

$$K = I_0 + I_1 + \ldots + I_{N-1}$$

  - ✓ Where K is the capital stock, aggregated over the current period investment I_0 and all other investments in $N-1$ prior periods

Appendix: Depreciation Assumption: Straight Line

- With the straight-line depreciation assumption, the rental price for a new asset is:

$U_t = (1+r)^{-1}[r + N^{-1} - tN^{-1}r]P_0 \quad for \ t = 0,1,\ldots,N-1 \ and$

$U_t = 0$ for $t = N, N+1$

- Efficiency declines linearly until the asset is retired, and again is determined by the service life of the asset, although efficiency decays in equal increments $(1/T)$ each year

$\phi_0 = 1, \phi_1 = 1 - \left(\frac{1}{T}\right), \ \phi_2 = 1 - \left(\frac{2}{T}\right), \ldots, \phi_{T-1} = 1 - \left(\frac{T-1}{T}\right), \phi_{T+t} = 0$

- This efficiency pattern is completely determined by the service life of the asset, although efficiency decays in equal increments $(1/T)$ each year
- With the straight-line depreciation assumption the capital stock model is:

$$K = \left(\frac{1}{N}\right)[NI_0 + (N-1)I_1 + (N-2)I_2 + \cdots + (1)I_{t-N}]$$

✓ Where the service life of the asset is *N*.

Appendix: Depreciation Assumption: Geometric Decay

- The rental price for a new asset is equal to:

$$U_0 = (1+r)^{-1}(r+\delta)P_0$$

✓ Where U_0 is the rental price (user cost) and P_0 is the asset price at time zero (that is, when the asset is new). The real interest rate is r, and the constant rate of depreciation is δ

- The productive capacity of the asset decays at a constant rate, $\delta = \frac{\phi_{t-1} - \phi_t}{\phi_{t-1}}$, giving an efficiency sequence:

$$\phi_0 = 1, \phi_1 = (1-\delta), \phi_2 = (1-\delta)^2, \ldots, \phi_t = (1-\delta)^t$$

✓ Characterized by the decay rate δ rather than the service life of the asset

- The net capital stock model is appropriate for aggregating vintages of capital stock:

$$K = I_0 + (I-\delta)I_1 + (1-\delta)^2 I_2 + \cdots + (1-\delta)^t\, I_t$$

✓ Where K is the capital stock, aggregated over all vintages, I_0 is the new investment in the asset in the current period, and I_t is the vintage investment that occurred t periods ago (for $t = 1, 2, \ldots$,t)

Appendix: Best Practices – Output Measurement

TFP Variable	Variable Choice	Potential Bias	Recommendations
Output	Measure of output.	Different output measures (such as volume growth or customer count) can cause differences in TFP, with the direction and magnitude of the bias depending on the trend captured by the output measure. For example, volume growth can increase revenues more than costs if volumetric charges are high, creating a positive bias in TFP. Alternatively, volume growth can be slowed by conservation and demand management programs, creating a negative bias in TFP.	Output indexes can consist of more than one output measure to incorporate both customer- and sales-density variables for measuring output for TFP analysis. Many TFP studies use a mix of output measures (number of customers, line miles, peak usage, etc.) in addition to the traditional output measure (kWh) to address these and other changing output trends in the electricity industry. Sensitivity analyses can be performed to assess the sensitivity of TFP growth to various output measures.

Appendix: Best Practices – Labor, Materials and Services Measurement

TFP Variable	Variable Choice	Potential Bias	Recommendations
Input	Measure of labor.	Most debate over labor measurement is over accurate measurement of labor quantity (i.e., FTEs) or selection of labor price indexes.	Methods should be transparent and replicable.
Input	Measure of materials and services.	Most debate over materials and services is over which expense categories are included or excluded, as well as appropriate price indexes.	Methods should be transparent and replicable. Sensitivity analyses can be performed over inclusion or exclusion of various expenses.

Appendix: Best Practices – Capital Measurement

TFP Variable	Variable Choice	Potential Bias	Recommendations
Capital	Choice of benchmark year.	Measurement error in starting capital cost and quantity can create positive or negative bias in TFP estimates.	Benchmark year should allow for many years of plant additions to minimize measurement error.
Capital	Gross or net value of plant in the benchmark year.	Downward bias in TFP trend if net plant value underestimates capital quantity.	Both methods have been used in TFP analyses. The gross capital stock model is appropriate for one-hoss-shay depreciation assumption and the net capital stock model for the geometric decay depreciation assumption (see Diewert and Lawrence 2000). However, existing TFP studies do not always align with the literature in their choice of gross or net plant value. Sensitivity analyses can be performed to determine impacts to TFP from using gross or net value of plant.
Capital	Depreciation method.	Different depreciation methods can result in different capital quantity and price valuations. All three methods (straight-line, one hoss shay, geometric decay) are utilized in TFP studies. The one-hoss-shay method is more sensitive to the useful life of the asset than the geometric decay assumption; however Diewert and Lawrence (2000) found differences in average TFP growth rates from using the three different depreciation assumptions were small. However, because the share of capital tends to be large in electricity sector TFP studies, differences in capital valuation may be important to overall TFP.	Depreciation assumption should best reflect the underlying depreciation profile of the asset. Capital quantity and price indexes should be consistent (i.e., reflect the same depreciation assumptions). Sensitivity analyses can be performed to determine impacts to TFP from using different depreciation assumptions.
Supplemental Capital	Capital tracker.	Although not a potential bias for TFP, capital trackers can weaken incentives for capex containment.	Consider the "effective" X-factor: $X' = X - K$ Consider designing superior incentives for supplemental capital plans.

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Appendix: Best Practices – Data and Sample

TFP Variable	Variable Choice	Potential Bias	Recommendations
TFP Data	Quality of data available for the sample of selected firms and their input and output data.	Index methods are sensitive to measurement error. The direction and magnitude of the bias will depend on the underlying measurement error.	-Publicly available, standardized data (such as those datasets available from FERC or other government agencies) are desirable. -Assumptions with respect to data source selection should be documented. Any changes to the data should be documented. -If measurement error is a significant concern, econometric approaches to TFP are desirable.
Inflation Indicator	Industry-specific or macroeconomic inflation indicator.	With a macroeconomic inflation indicator, if the input price trend of the economy rises more rapidly than that of the electric industry, the X-factor will be larger, slowing price or revenue growth.	When a macroeconomic inflation index such as the GDPPI is used to measure inflation, there is an additional term known as the input price or inflation differential that must also be estimated.
Length of Study	The X-factor can be calibrated to reflect short- or long-run trends depending on the length of the study.	Short-run trends can be more volatile due to input price or demand fluctuations; long-run trends can smooth these effects. If there is input price volatility, basing the X-factor on long-run trends can cause financial distress for utilities.	The length of the study should be long enough to smooth out volatility in outputs and costs, but reflective of the growth trend that is likely to occur during the performance-based regulation (PBR) period. If it is believed that long-term growth periods are unstable, statistical tests can be used to determine if a structural break has occurred.
Sample Selection	Number and characteristics of included utilities.	In North America, the X-factor is commonly determined based on the productivity growth of a representative sample of firms that constitutes the electric industry. If the productivity trends are dominated by a handful of utilities, TFP may be biased.	When the TFP metric is productivity growth, heterogeneity across firms largely vanishes, and it is advisable to use the largest possible sample of firms. If there is reason to believe that heterogeneity persists, a sample can be restricted to more comparable firms; however, care must be taken to account for exogenous factors that drive productivity differences across firms. For example, firms should face similar productivity growth drivers, such as external business conditions. TFP can be calculated on different sub-sections of samples to understand the impact of particular sample choices.

Appendix: Best Practices – Weighting Methods

TFP Variable	Variable Choice	Potential Bias	Recommendations
Index Weights	Revenue or cost share.	Revenue or cost shares are common and inferred by using econometric models if specific prices are not available. Inaccurate weights can cause changes in output or input indexes that will affect TFP measures.	The choice of revenue or cost share depends on the output or input variable chosen. For example, volume (MWh) as an output measure is typically weighted by its revenue share from customer sales, whereas the number of customers or peak demand is typically weighted by an econometrically inferred cost share. Methodologies for determining revenue or cost shares should be clearly documented and make sense based on the data used to determine the shares.
Index Weights	Chained or multilateral.	Chain-weighted or multilateral index weights are common in TFP studies. The choice of chained or multilateral index can affect TFP as both cost shares and relative growth are computed differently. Chain-weighted index weights are calculated for consecutive periods, whereas multilateral indexes are computed relative to the average firm.	With TFP growth either method is appropriate. With TFP levels, only the multilateral method is appropriate. TFP levels are sometimes used in TFP studies to compare absolute levels of firm productivity. Sensitivity analyses can be performed to assess the sensitivity of TFP growth to various index weighting procedures.
TFP Trends	Arithmetic or weighted average.	Methods to average the TFP trends vary, for example, weights can be a simple arithmetic average or more weight can be given to more similar firms or more recent years.	Sensitivity analyses can be performed to determine impacts to TFP from different weighting methods.