Submission to Australian Energy Market Commission: Design Discussion Paper

Pacific Economics Group, LLC

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1. INTRODUCTION

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

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

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

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

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

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

2. TFP SPECIFICATION

Page 25 of the Discussion Paper poses two questions for comment and discussion. They are:

- What should be the correct specification of inputs and outputs to be used to calculate the TFP growth estimate?
- Is the proposed set of criteria to identify the correct specification appropriate?

The proposed criteria referenced in the second bullet point are presented on pp. 26-27 of the Discussion Paper. They are replicated below:

- results in a stable index over time
- creates no systematic bias in the TFP growth estimate
- is consistent with promoting economic efficiency and does not result in any perverse incentives
- is consistent with the service provider's regulatory asset base; and
- results in reporting requirements which are proportionate and not onerous

My short answer to the second question above is that these criteria are generally appropriate but not complete. Importantly, these criteria do not include the single most important issue that must be addressed when identifying the correct TFP specification for a TFP-based regulatory option. I explore this point immediately below, and this analysis leads directly to the correct output and input quantity specification. I then return to the specific criteria that are proposed in the Discussion Paper.

The Rate of Change in Prices in TFP-Based Regulation

A well-defined conceptual paradigm is used to identify the target rate of change in utility prices under TFP-based regulation.[1] This paradigm says that utility prices under a

[1] For the present purposes, I will exclude the portion of the paradigm that concerns the "consumer dividend" or "productivity stretch factor" component of the X factor that is imposed in many North American regulation plans. This component reflects the acceleration in a utility's TFP growth, relative to historical norms, that is expected to result from the change from cost of service regulation to a more high-

TFP-based regulatory plan should grow at the same rate as the *observed historical* rate of change in *industry* unit costs. The reason is intuitive: the industry change in unit cost is entirely "external" to the utility in question. The utility therefore has strong incentives to control the growth in its own unit cost, since it retains the savings as profit.

Building block regulation also establishes a link between price changes and changes in unit cost, but it differs from the linkage created in TFP-based regulation in two main respects. First, building block regulation is established on a *business-specific basis*: prices are set to reflect the expected unit costs changes of each specific utility rather than the industry on average. Second, building block regulation is set on a *forward-looking* or prospective basis, whereas TFP-based regulation is based on observed, historical trends.[2]

These differences in how the linkage is established between prices and unit costs have important implications for the incentive properties of the two regimes. Since building block regulation applies on a company-specific basis, it creates generally weaker incentives than the industry-based TFP alternative, which more directly replicates the outcome of competitive markets where firms' profits depend on their performance relative to rivals in the marketplace. In addition, since building block regulation uses forward-looking information, it creates incentives to game price trends (*e.g.* through cost forecasts) that are entirely absent in TFP-based regulation. A forward-looking, company-specific regulatory mechanism also requires far more information and is therefore more burdensome and costly to administer than the TFP-based approach, where price changes are based on observed industry trends.

The linkage between prices and industry unit costs also has direct implications for how TFP should be measured in TFP-based regulation. Simply put, TFP must be specified in such a way so that, when it is combined with observed historical changes in

powered incentive regulation approach. This component is not relevant in the current context since Australian energy distributors are not switching from cost of service regulation to incentive regulation.

[2] Implicitly, the TFP-based approach assumes that the industry's observed, historical past is a reasonable proxy for the cost trends that may be expected in the future. This assumption may not be valid for all distributors at all times, and some TFP-based plans have included features such as capital modules to allow for diversity in utility expenditure profiles or other circumstances. Provisions to allow for distributor diversity are also allowed in the model put forward in the Discussion Paper, and are discussed in the following section.

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

The Correct TFP Specification

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

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

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

Other submissions in New Zealand's current proceeding have provided additional evidence in support of using billing determinants to measure outputs in TFP studies. For example, PricewaterhouseCoopers (PwC) wrote:

> 'It is submitted that the question of what definition of output is 'right' for regulatory purposes is not the definition that reflects 'exactly what service does an energy distribution business provide' or the service that reflects best the utility gained by customers. Rather the right definition of output is the one that is most likely to generate a price path that aligns an EDB's revenue stream with its costs (that is, achieves ex ante financial capital maintenance). Assessed against this objective, it seems self evident that using a measure of output that does not reflect how prices are set can lead to obvious errors (that is even if there is only one regulated firm). This argument is explained most simply by providing a simple example, which is set out in Box 1 below.'

PwC's example was effectively unrebutted by Economic Insights, since their response appealed to econometric techniques which were not, in fact, used to estimate TFP rather than actual index-based example that PwC constructed. The AEMC has also ruled out using econometric methods to estimate TFP for any TFP-based regulatory option that may be added to Australia's regulatory framework.

When addressing output choices, the Discussion Paper notes that the ESC recommends using billing determinants to measure outputs and says that its rationale "that actual revenue shares must be used to be consistent with allocative efficiency seems theoretically correct. However from a practical perspective, given the processes and considerations that go into establishing tariff structures, the current revenue shares may not appropriately reflect the value placed on each output by the consumer" (p. 26). It must be recognized, however, that the allocative efficiency criterion used by the ESC in this context does not refer to the efficiency of pricing structures, but rather to the broader

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Theoretical Report, and which was used in equation (157) that I was previously discussing. This opex cost function includes capital as an independent variable, whereas the total cost function of course does not include inputs as independent variables. I believed this was clear in the context, especially given the fact that I was referring to EI's own statement that "the marginal costs of each input (including capital inputs) is assumed to equal its market price," but it could have confused some readers familiar with the theoretical specifications of cost functions (the statement that "the derivation of this marginal cost occurs only in the theoretical realm of the production function" may have also been somewhat confusing, since I was previously discussing cost functions, but marginal costs are in fact more frequently derived from production than cost functions). These clarifications will hopefully clear up any technical confusions regarding terminology, but they do not have any bearing on the analysis or conclusions presented in that submission.

allocative concern that industry revenues change at the same rate as the growth in industry costs. This is identical to the criterion that PwC used for recommending outputs that are "most likely to generate a price path that aligns an EDB's revenue stream with its costs (that is, achieves ex ante financial capital maintenance)." Both PwC's example and the indexing logic discussed in the ESC submission both support the conclusion that a utility's actual billing determinants will better promote this objective.

EI has also critiqued using billing determinants, weighted by their respective revenue shares, to measure outputs in TFP studies. They favor "functional" outputs that are not actually billed to customers, particularly when a single X factor will be applied to multiple companies. In both New Zealand and the AEMC Discussion Paper, this view has been supported with reference to the Australian experience. For example, EI has written:

> It may be helpful to provide a concrete example of the distortions that can arise from using simple revenue weights and billable outputs to form an estimate of TFP growth that could be used in setting an X factor. The Australian states of Victoria and Queensland have diametrically opposed charging practices. In Victoria the EDBs place the majority of their charges on the variable components of throughput and, to a lesser extent, peak demand. In Queensland, on the other hand, EDBs place nearly all their charges on fixed components, ie there are negligible throughput and peak demand charges. Throughput has been growing faster than customer numbers in recent years. If billable outputs and revenue weights were used to form the average TFP growth rate across these two states and a common price cap applied based on this then the resulting estimate would be appropriate for none of the EDBs. This is because the output weights used to form the average industry TFP estimate would reflect to any meaningful extent neither the pricing nor the underlying costs of any of the EDBs given the diametrically opposed charging practices of the two states. If the alternative approach of using functional (or economic) outputs (of which billable outputs are a subset) and allowing for both costs and prices in forming output weights is used, then all EDBs are put on an even footing and the resulting TFP estimate will be more appropriate for use in setting a common X factor across all the EDBs

Simply in terms of the algebra, it is true that if two companies differ in terms of the relative revenues collected from two outputs, and those outputs grow at different rates, the revenues for these companies will grow at different rates. My recommended output specification would lead to average revenue (and margin) growth that therefore differs from the revenue (and margin) growth for either of the companies. But this result stems entirely from the fact that a single X factor is being applied to the entire industry, so it is impossible to tailor the value of X to be specific to individual company circumstances (which would be a difficult and contentious exercise to attempt).

EI's "functional output" also does not solve this problem. Companies would still start with differences in rate designs and experience different rates of output growth, which would lead to the same outcome of having different rates of revenue and margin growth. If a non-priced "functional" output is added to the TFP specification, the only effect will be to drive a wedge between revenue and cost growth for the industry as a whole (unlike my recommended approach, where industry revenues and costs will necessarily grow at the same right), while doing nothing to correct the "problem" for individual companies. EI's analysis therefore never demonstrates that including unbilled outputs in the output specification ensures that "all EDBs are put on an even footing."

It is noteworthy, however, that the model put forward in the discussion paper does allow for a capital module, as well as some business specific adjustments to industry TFP trends in limited circumstances. This is a more flexible application of a TFP-based regulatory approach than is used in New Zealand, where a single X factor applies to all electricity distributors. This more flexible approach to TFP-based regulation thereby further undermines EI's rationale for using functional rather than billed outputs, since it is predicated on the assumption that a single X factor will necessarily apply to the entire industry.

The Criteria Proposed by the Discussion Paper for Evaluating Output and Input Choices

With this background, I now return to the criteria proposed in the Discussion Paper for determining the appropriate TFP specification. In my opinion, the criteria discussed above are more fundamental than those proposed by the AEMC and, indeed, I believe they are sufficient for concluding that my recommended specification is correct for a TFP-based regulatory option. Nevertheless, this specification is also preferred relative to EI's alternative (or at least is as preferred) using the criteria advanced in the Paper. For example:

- **Results in a stable index over time**

  My specification is preferred on this criterion, since it will lead to revenue changes that track cost changes for the industry as a whole on an *ex ante* basis. This leads to more stability over the multi-year operation of an indexing plan than an indexing mechanism where revenues do not track costs. The latter application would, in turn, invite greater price adjustments when plan terms are reviewed. This will not only increase instability, but will also reduce the attractiveness of the TFP-based regulatory option.

It may be argued that my recommended TFP specification is less stable than one which uses functional outputs, or puts less weight on more variable outputs like energy deliveries, since the latter specification may lead to smaller year-to-year changes. However, I believe this argument is specious, since these year to year changes are part of the reality of utility businesses and ignoring these revenue (and cost) changes will cause more weight to be placed on price reviews when controls expire, as well as lead to greater price adjustments at those reviews. My recommended specification will track actual year to year changes in revenues and costs, but will also smooth these changes since they will be averaged with fluctuations that move in the opposite direction as well with the experience of more "typical" years. On average, however, the specification will lead industry revenue to track industry cost, which is the most important criterion to be used for evaluating stability.

- **Creates no systematic bias in the TFP growth estimate**
  In a sense, this criterion begs the question of how the "bias" in TFP growth will be defined and evaluated. However, I believe the fundamental criterion presented above can be used as the appropriate standard for judging whether the TFP specification is biased for a TFP-based regulatory application. My recommended specification clearly satisfies this criterion, while EI's does not.

I also believe that using auxiliary regressions to estimate the TFP trend, rather than measuring TFP directly using the estimated TFP index values, can create a type of bias. Consider the following example: suppose the data below correspond to the measured TFP level indexes for two companies over the relevant time frame.

Year	Company One	Company Two
1	1.00	1.00
2	1.02	0.90
3	1.04	0.935
4	1.06	0.97
5	1.08	1.005
6	1.10	1.04
7	1.12	1.075
8	1.14	1.10
9	1.16	1.145
10	1.18	1.18

It can be seen that Company One and Two start with the same initial TFP level in year one and end with the same TFP level in year 10. In the intervening years, Company One's TFP is greater than Company Two's. I believe it would not be sensible to argue that Company Two achieved higher TFP growth than Company One, since its TFP level was equal to or lower than Company One's in every year. However, it would be reasonable to say that Companies One and Two had identical TFP growth rates, but the paths that they took for achieving those growth rates differed.

If TFP growth was measured directly as the growth rate in the measured indices between periods one and ten, the growth rates would (obviously) be the same for Companies One and Two. This is the approach that I recommend for estimating TFP growth. However, it is easy to verify that if TFP growth is measured by the estimated slope of a linear regression of TFP on time, annual TFP growth for Company One will be 2% while annual TFP growth for Company Two will be 2.76% (and this estimate will be statistically significant at the 1% level).

This result is both implausible and counterintuitive, and it demonstrates the "bias" that can result from using auxiliary regressions to estimate TFP growth. It also shows that this bias does not depend only on whether the first and last observations in the TFP series are outliers. In general, TFP trend estimates will be more sensitive to the temporal distribution of the TFP index values under a regression approach rather than by calculating the annual growth rate using measured TFP index values.

- **Is consistent with promoting economic efficiency and does not result in any perverse incentives**
  My specification and the TFP specification recommended by EI will both apply to industry TFP trends and are therefore "external" to any particular utility. In that sense, both specifications create the same incentives for cost efficiency. However, because my specification will allow revenues to track costs for the industry as a whole, all else equal, it will allow less weight to be placed on price reviews that occur when the plan expires. This should promote greater dynamic efficiency compared with EI' s alternative. The ESC submissions contain extended discussions of the dynamic efficiency benefits that can stem from the application of TFP-based regulation.

- **Is consistent with the service provider's regulatory asset base**
  My recommended specification is clearly consistent with the service provider's regulatory asset base, since it uses initial values of the asset base and subsequent additions to asset base to measure capital input quantities. Moreover, my specification uses regulatory depreciation (which is reflected in changes in the asset base) to measure depreciation

rates. The formula used to calculate changes in rates therefore uses the same data, and is internally consistent with, the methods used to set rate levels when a TFP-based regulatory plan expires.

EI's proposed TFP specification is clearly inconsistent with the service provider's regulatory asset base. EI proposes to measure capital using physical metrics, which are not the basis for regulatory asset values. It also assumes that there is no depreciation in capital (one hoss shay depreciation), which is clearly incompatible with the regulatory depreciation that will be recorded and booked by companies while a TFP-based regulatory plan is in effect. Under EI's proposed specification, the formula used to calculate changes in rates will therefore use data that are different from, and internally inconsistent with, the methods and data used to set rate levels when the TFP-based regulatory plan expires.

As the Discussion Paper noted, EI's proposal to measure capital using physical metrics was recently proposed and rejected in a TFP-based regulatory proceeding in Ontario. The Ontario Energy Board singled out this feature of the TFP specification as being its greatest concern which led the proposal to be rejected. This was largely due to the fact that physical capital metrics were inconsistent with the regulatory asset values used to set initial rates.

It should also be noted that physical capital metrics will not reflect the impact of capital replacement expenditures on utility's unit cost as directly as monetary capital values. This is clearly a relevant concern if a "wall of wire" needs to be replaced in the near future. I discuss this issue in more detail in Section 4.1 of Appendix Three.

- **Results in reporting requirements which are proportionate and not onerous**

  My recommended TFP specification can be implemented immediately using data that are already collected and reported for regulatory and tariff compliance purposes. It therefore will impose minimal reporting requirements. EI's recommended specification requires the calculation of "functional" outputs that are not currently measured and will require some effort and expense to construct. EI's recommended specification also uses physical capital measures that are not currently reported on a standardized basis for regulatory purposes. The EI specification will therefore impose greater and more onerous regulatory reporting requirements.

3. DESIGN ISSUES FOR TFP-BASED REGULATORY OPTION

I have relatively few comments on the proposed design of the TFP-based regulatory model. I agree almost entirely with the “Overview of TFP Design” presented on pp. 11-15 of the Paper, as well as most of the Paper’s subsequent elaboration of these points. This model strikes an appropriate balance between having a rigorous, well grounded regulatory framework with the need to have a flexible application of the TFP-based option to the diverse circumstances of Australia’s energy utilities. The stability embedded in the framework will reduce the incremental costs of developing and administering the option, while the potential to tailor TFP-based regulation to certain, well-defined circumstances of distributors will enhance the incremental benefits. Below I respond to the specific design questions that are posed in the Paper.

Page 28:

- Is a single X factor for all regulated service providers in the sector appropriate? Or, would it be necessary to divide the sector into four subsets according to operating environment conditions or customer density?

  A single X factor for all regulated service providers in a sector is appropriate. Dividing the industry into any number of subsets:

  - Is not necessary to have an appropriate measure of the industry TFP trend
  - Is not necessary to reflect the conditions of individual distributors, especially in light of the other mechanisms that are available for accommodating these conditions, such as the incremental capital module
  - Will dramatically increase the complexity and costs of administering a TFP-based regulatory option
  - May introduce incentives for gaming *e.g.* by companies lobbying the AEMC (or AER) to move them into the industry sub-set with the lowest TFP trend, or to create new industry sub-sets
  - Is not justified based on current evidence on intra-industry differences in potential TFP growth

Page 36:

- What would be the impact on service providers' incentives to improve performance under this design example (for setting the initial price cap)?

  There would be some negative impact, but since the review will only examine current period costs I believe it would be relatively small. Moreover, I believe that price reviews can become increasingly light-handed over time as regulators and companies become more familiar with the TFP-based regulatory option. Reviews are also likely to be relatively light-handed if the TFP specification leads industry revenues to track industry costs, and this objective will be promoted by my TFP specification.

- What would be the impact on service providers' ability to recover efficient costs under this design example?

  Companies will be able to recover their efficient historical costs under this example. They will also have the ability to recover their efficient costs under the TFP-based regulatory option, particularly since it includes an incremental capital module.

- Should the regulator have the discretion to refer to other information, such as forecast costs, when setting the initial price or revenue cap?

  No. The initial price cap should not be based on forecast costs.

Page 40:

- Should a regulatory period longer than five years be set in the NER and NGR for a service provider using a TFP methodology?

  I believe it is appropriate for service providers and regulators to have the same level of discretion with regard to plan term that currently exists.

Page 41:

- Are any amendments to the current provisions required to ensure compatibility with a TFP based framework?

  Not that I am aware of.

- How can the possibility of double counting pass through events under a price path will a rolling X be addressed?

  If it is an entirely new cost, there are no double counting concerns, since the cost was not previously reflected in the initial rates that are subject to indexing. If it is not a new cost, I co-authored an article that outlines a methodology that eliminates such double counting and which I believe would prove effective in the current circumstances. This article is "The Treatment of Z Factors in Price Cap Plans" (with Mark Newton Lowry), *Applied Economics Letters*, 2: 1995.

Page 43:

- Is a capital module required and, if so, how should such a module be designed for Australia? In particular, should the module use agreed (and prudently assessed) forecast or actual expenditure amounts?

  I believe a capital module is required. The AEMC has already examined the capital module that was approved in Ontario. I would recommend that the Ontario module be adopted in Australia, with two modifications. First, there was no empirical foundation for the 20% "buffer" that was included in the company-specific threshold formula, so this buffer should be removed. Second, the Ontario module allowed for both historical and forecast capital expenditures; in the interest of simplicity and to reduce administrative costs, I would recommend that the module be applied only to the prudent costs of actual (rather than forecast) capital investments.

Page 45:

- Is there a need for an off ramp mechanism to be included in a TFP methodology? Does its use inappropriately reduce incentives?

  I believe an offramp is an appropriate provision in a TFP-based model and should be included. The offramp protects against unforeseen circumstances and does not materially impact incentives.

Page 46:

- Should a service provider be able to select the form of the X factor? Or does this provide a level of uncertainty that is undesirable in the operation of a TFP methodology?

  Yes, a service provider should have the option of selecting either a fixed or rolling X factor. In general, providing options to service providers will reduce, and not increase, the level of uncertainty associated with the regime. While the value of a rolling X can clearly not be forecast with certainty, this will be a risk that companies selecting a rolling X factor have chosen to assume. Accordingly, if a service provider elects a rolling X factor, it should generally be expected that it will accept the values that result from updated applications of the rolling TFP methodology. While use of offramps under a rolling X factor should not be prohibited, companies should generally have a higher burden of proof for demonstrating why such an offramp may be necessary due to, say, an unexpected increase in the X factor, since this would represent a risk that the company voluntarily assumed.

Page 54:

- Is the rationale for allowing business specific adjustments to the X factor correct?

Yes. Business-specific adjustments to the X factor should not be ruled out entirely, but there should be a strong presumption that they are not necessary. There must also be strong evidence that such adjustments are necessary on a rate of change, and not simply a levels, basis.

4. Miscellaneous Issues

At various points, the Discussion Paper makes a few statements that are somewhat ancillary to the main focus of the Paper but merit comment to ensure that there are no misunderstandings regarding my recommendations for this review. This section will address those statements.

On page 3, regarding the criteria used to guide the AEMC's review, the Paper says that "(c)onsideration has not been give to the adequacy of any existing data-set. Rather, the design has been developed under the assumption that the necessary data would be available. The TFP methodology should determine the required data rather than the existing data-set dictating the design of the TFP methodology." I concur entirely. Moreover, this criterion has underpinned all of the TFP research I have undertaken on Victoria's electric and gas distributors. Each of these TFP specifications was pursued because they were appropriate for TFP-based regulation, not because the data were (in fact) available to estimate these specifications. I believe this attitude is also evident in my reports from Victoria, but it is important to clarify this point since some observers may believe that TFP specifications flowed from the data availability rather than vice versa.

I also support the Paper's conclusion (p. 19) that utility industries are never likely to be in a "steady state," so that any TFP-based methodology must be able to cope with variations in expenditure profiles across companies. The proposed incremental capital module clearly satisfies this objective. The "steady state" objection is overstated in any case but, especially with the addition of a capital module, it is not a sufficient reason to reject adding a TFP-based option to Australia's regulatory framework.

On page 53, when discussing input price growth, the Paper says "(r)esearch undertaken by PEG for the ESC has indicated that input prices for Victorian electricity distribution businesses changed at a rate approximately equal to the CPI. Therefore it could be argued that the CPI should be used as a proxy for industry input price growth." While the AEMC cites our research in this statement, it is important to point out that PEG never actually makes this argument or concludes that the CPI is an appropriate proxy for input price growth for utility industries. In fact, in our TFP work we endeavored to obtain the best possible measures for trends in both operational and capital input prices using publicly available indices.

I therefore agree with the Discussion Paper's conclusion that a TFP-based methodology should not assume that the CPI is a good proxy for industry input price inflation, and the Rules need to specify a term that reflects the difference between the growth in input prices for the industry and the overall economy. It would be most straightforward for this differential to be measured directly, over the same period used to measure TFP growth, and updated according to agreed formulas as more data become available. Particularly because this is an option that will be maintained and available to utility industries on an ongoing basis, I believe it is important for the formulas used to compute the input price and TFP differentials to be as "hardwired" as possible. Doing so will create more certainty and increase the viability of the option than a more discretionary approach where, for example, the input price differential could be set to zero even if the measured differential was non-zero due to a variety of factors that are expected to impact future input prices. Introducing this type of discretion can substantially increase the incremental costs of administering the TFP-based regime and will reduce the potential benefits of having a ready, "off the shelf" option available to the companies. This situation also differs from a situation where TFP-based option is not an option and decisions on the input price and TFP differentials will necessarily determine a utility's allowed prices. As in the current proceeding in New Zealand, it can be appropriate for the regulators to exercise discretion in this situation rather than applying a more formulaic, mechanistic approach.

Page 59 of the Paper says "two commonly used depreciation profiles are 'one hoss shay' depreciation where the service potential quantity remains relatively constant over the asset's life and declining balance or 'geometric' depreciation where the service potential declines by a given percentage each year." It should be noted that there is also a third option, which is to use the regulatory depreciation profile. This is, in fact, what I have used in the TFP studies that I have presented in Australia and New Zealand.

Finally, Section D.2 of Appendix D presents some alternative formulas for calculating the X factor. These formulas were first presented in a regulatory context by

EI in the current TFP-based proceeding in New Zealand. While these formulas are apparently not playing an explicit role in the model put forward by the AEMC, I do not believe they are analytically sound since they were derived using unrealistic assumptions. My analysis of this issue is presented in Appendix Four.

5. CONCLUDING COMMENTS

The AEMC's Discussion Paper represents an important step forward in designing a practical and credible TFP-based regulatory option. The model put forward appropriately balances the objectives of creating a stable regulatory framework and allowing for a flexible adaptation of the TFP-based option to individual utilities. The main unresolved issue in the Paper is the specification to be used to estimate TFP itself. I believe a careful review of this topic reveals that the correct TFP specification is the one that has been put forward by the ESC. In addition to being more compatible with the criteria presented in the Discussion Paper, only this specification satisfies the fundamental rationale and indexing logic that underpins the TFP-based regulatory approach. I believe that the general TFP model put forward in the Discussion Paper, coupled with the recommendations presented here on specific design features and the ESC's recommended TFP specification, will maximize the potential incremental benefits that can result from adding a TFP-based option to Australia's regulatory framework while minimizing the associated incremental costs. I therefore recommend that this approach be adopted by the AEMC in this review.

APPENDIX ONE: OUTPUT SPECIFICATION

(*Note: the following discussion originally appeared as Appendix One in Kaufmann, L and D. Hovde.,* ***X Factor Recommendations for New Zealand Electricity Distribution Price Controls****, July 2009, pp. 38-42)*

Indexing Logic, Outputs and Output Weights

PEG believes that there is a strong analytical foundation for determining the choices for outputs and inputs for in CPI-X indexing plans for EDBs. We believe this foundation flows directly from the indexing logic which establishes the link between industry TFP growth rates and the calibration of tariff indexing formulas. This indexing logic is generally accepted in Australia and New Zealand, but its implications for output and input choices are not widely recognized. We believe this Review by the Commission provides an excellent opportunity to explore this issue and, in the process, ideally resolve many of the debates regarding TFP measurement that have taken place to date in ANZ. We present this logic below and then discuss its implications for appropriate output choices in TFP measurement.

The indexing logic relies on what is sometimes referred to as the competitive market paradigm *i.e.* that utility tariff adjustments should be set at a rate that is consistent with how prices evolve in competitive markets. The indexing logic therefore examines long-run changes in revenues and costs for an industry. In the long run, the trend in revenue (R) for an industry equals the trend in its cost (C).

$$Trend\ R = Trend\ C \qquad \textbf{(1)}$$

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

$$Trend\ R = Trend\ P + Trend\ Y \qquad \textbf{(2)}$$

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

$$Trend\ C = Trend\ W + Trend\ X \qquad \textbf{(3)}$$

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

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

This is the basic result of the indexing logic. It shows that the change in an industry output price index can be decomposed into changes in the industry's input price index minus changes in its TFP index. When this result is applied to utility regulation, it implies that allowed changes in utility prices (the left-hand side variable in (4)) can be linked to industry input price inflation minus changes in industry TFP. If the chosen inflation factor (such as the CPI) is a good proxy for long-run trends in industry input prices, then it is appropriate to set the X factor equal to the trend in the regulated industry's TFP.

These results, which show the usefulness of TFP trends for tariff adjustments, are generally understood, but the implications of this same indexing logic for appropriate TFP measurement are less recognized. For example, while equation (1) is only the starting point for the analysis, it has two important implications. First, it focuses only on the rate of change in prices and revenues. The indexing logic applies only to calibrating the terms of tariff adjustment formulas, not setting rate levels at the outset of an indexing regime. The competitive market paradigm therefore focuses on only a narrow issue – how revenues and costs evolve over time in competitive markets – and works from this premise towards deriving implications for the appropriate calibration of changes in tariffs for regulated markets. Equation (1) has no implications for the regulated industries' price levels; for example, it never says that regulated prices should approximate marginal costs, as occurs in perfectly competitive markets. This distinction between what the paradigm implies for appropriate price changes and price levels is sometimes not appreciated.

Second, equation (1) has implications about the dimensions of efficiency which need to be captured in a TFP measure used to adjust tariffs. Economists often distinguish between productive efficiency and allocative efficiency. Productive efficiency focuses on cost efficiency *e.g.* whether firms use the minimal number of inputs to produce a given level of output. Productive efficiency is focused exclusively on costs, which appear only on the right-hand side of equation (1). If an industry is productively efficient, then the trend rate of change in costs on the right-hand side of (1) will be the lowest possible change in costs that is necessary to satisfy the industry's changing output (given existing technology).

There are a number of components of allocative efficiency, but in a regulatory context one important consideration is whether changes in revenues approximately track changes in its costs. Equation (1) clearly embodies this dimension of allocative efficiency on an industry-wide basis. This is obvious since the change in the variable on the left-hand side of (1) [revenues] is explicitly set equal to the change in the variable on the right-hand side of (1) [costs].

The indexing logic which links TFP trends to changes in tariffs begins with equation (1). Our exposition above indicates that equation (1) necessarily reflects both allocative efficiency (in the relationship between changes in revenues and changes in costs for the industry) and productive efficiency (with respect to the efficient change in costs that appears on the right-hand side of (1)). It follows that the TFP measure that emerges from the further elaboration of this logic – and which appears in equation (4) - must also embody both productive and allocative efficiency. Importantly, the appropriate measure of industry TFP growth that is used in TFP-based regulation must be one that would tend to promote changes in industry revenues that approximate changes in industry costs. It should be emphasized that this relationship applies to the *industry* and not an individual utility; any individual utility would still have incentives to keep its cost growth below what is reflected in the industry-wide norms, as is the case in competitive markets.

This important point has not been appreciated in the TFP debates that have taken place to date in ANZ. For example, much of the criticism of PEG's TFP research in Victoria has implicitly been motivated by the concern that it does not adequately measure productive efficiency, but these critiques do not consider the (at least) equally important issue of allocative efficiency. For example, in arguing for its output specification (including the addition of a network capacity variable and the use of cost elasticities rather than revenue shares as weights), Meyrick and Associates has written that "the objective is to measure TFP which is output produced per unit of input (or total real cost)."[4] Meyrick has also written that "the objective of the X factor is to calculate achievable TFP gains going forward. As such, the use of cost elasticity shares to aggregate outputs in calculating TFP is unambiguously preferable to revenue shares which may bear little resemblance to relative costs."[5]

Both of these statements focus exclusively on the linkage between TFP and cost – or productive – efficiency. This focus is often warranted in academic research where the objective *is* to obtain the best possible measures of productive efficiency. But equation (1) makes it clear that this focus is not sufficient for TFP measures that are used to regulate utility tariffs, since an exclusive focus on productive efficiency would concentrate only on the right hand side of this equation. The TFP trend measures that appear in equation (4) of this logic, and which are used for utility regulation, must go beyond measuring productive efficiency to include allocative efficiency as well. The latter reflects the relationship between changes in costs and changes in revenues; this is an essential part of the indexing logic that cannot be ignored.

We next consider equation (2). This equation shows that the change in revenue can be decomposed into a change in output prices and output quantities. The change in output quantities in this equation is the same output quantity trend that appears in the TFP trend measure in equation (4). Equation (2) therefore draws a direct link between the outputs that are used to measure TFP and revenues. In other words, the outputs that are used in the TFP measure *must* have a direct link to the revenues of the regulated industry. If this was not the case, then the index decomposition in (2) – which gives rise to the output quantity index used in the TFP measure – would not be satisfied.[6]

More specifically, equation (2) has two direct implications for the output quantity specification. One is that the specific output quantities that are used to compute the output quantity index must be the billing determinants that are used in the tariffs for the regulated sector. No other output quantity measures can be compatible with equation (2)

[4] Meyrick and Associates, *Response to Pacific Economics Group 'Evaluation of Meyrick and Associates Review of PEG TFP Report*, Report prepared for AGLE, CitiPower, Powercor, TXU Networks and United Energy, 29 March 2005, p. 3.

[5] Meyrick and Associates, *op cit*, p. 4.

[6] More technically, equation (2) says that the revenue, price and output quantity indexes that are used in TFP-based regulation must satisfy what is known as the product test.

in the logic above. This can perhaps be clarified by considering a particular TFP controversy that has arisen in Australia. In its original TFP research for Victoria's electricity distribution sector, PEG measured output using the quantities that these utilities actually billed its customers for – customer numbers (via the customer charge), on-peak kWh deliveries, off-peak kWh deliveries and peak demands. Their rationale was that these are the billing determinants and hence the only quantities that are consistent with equation (2). Meyrick criticized this specification, in large part because it ignored what it called the network capacity output. Meyrick compared energy networks to roads, and said that electricity distributors were responsible for providing and maintaining this "road" but not responsible for the traffic (*e.g* the kWh deliveries) on that road. Meyrick claimed that PEG's TFP specification was deficient since it did not consider this important consideration, which is critical to how distributors actually operate and manage their businesses. Meyrick's critique could have had merit if the only objective of the TFP study was to measure distributors' how effectively managers are running their business *i.e.* their productive efficiency. But as our exposition of equation (1) indicates, this is not the objective for TFP measures that are used for rate adjustment mechanisms, which must consider both productive and allocative efficiency. Meyrick's network capacity output is not consistent with the allocative efficiency prerogative, nor is it consistent with equation (2), which links changes in utility outputs to changes in utility revenues. Distributors do not charge directly for the network capacity measure that Meyrick recommended, so there is no logical relationship between this output and distribution revenue. Thus while Meyrick's critique raised interesting points that may be relevant for academic research, they were not material for the specific objective of PEG's TFP study. In a TFP study used in CPI-X regulation, there must be a link between the outputs used in the TFP study and utility revenues, and only a utility's billing determinants can satisfy this criterion.

The second implication of equation (2) is that each billing determinant should be weighted by its revenue share when computing the output quantity index. Again, this is necessary for the changes in revenues to be decomposable into changes in output prices and output quantities. If output quantities were weighted by anything other than each output's share of revenues, equation (2) would not be satisfied (except by chance).

APPENDIX TWO: MEASUREMENT OF CAPITAL

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

PHYSICAL VERSUS MONETARY CAPITAL MEASURES AND ALTERNATIVE DEPRECIATION ASSUMPTIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

APPENDIX THREE: SUBMISSION TO NEW ZEALAND COMMERCE COMMISSION DRAFT DECISION

1. INTRODUCTION

In September 2009, the New Zealand Commerce Commission (the Commission) released its *Draft Decisions Paper: Initial Reset of the Default Price Quality Path for Electricity Distribution Businesses* (the Draft Decisions Paper). At the same time the Commission released the Economic Insights (EI) report *Electricity Distribution Industry Productivity Analysis: 1996-2008* (the EI Report). Both papers are primarily focused on developing draft recommendations for empirical values of the parameters used to reset the default price-quality path (DPP) for the electricity distribution businesses (EDBs). In doing so, both papers present some comments on the methodology that Pacific Economics Group (PEG) has recommended for estimating the EDBs' total factor productivity (TFP) growth.

The Electricity Networks Association (ENA) asked me to respond to these comments on PEG's TFP methodology. The ENA believes that any potential misunderstandings of PEG's TFP study should be addressed, even if there are no immediate implications for the DPP. A better understanding of the application of TFP to utility regulation should put the foundation for resetting the DPP on a more firm conceptual foundation and thereby promote regulatory stability. PEG's TFP research has been misinterpreted and mischaracterized in this proceeding, but addressing these misconceptions provides an opportunity to clarify the relationship between changes in regulated prices, unit costs and TFP for utility industries.

I begin by addressing the claims regarding the "indexing logic" and assumptions that underpin PEG's TFP specification. I then briefly discuss the theoretical framework which motivates EI's analysis and explain how EI's analysis is focused entirely on theoretical issues rather than practical TFP measurement. Next, I consider the extent to which the PEG and EI TFP methodologies address two very concrete regulatory concerns (reflecting capital replacement expenditures, and enabling industry-wide revenues to track changes in industry costs). The final section provides brief concluding remarks, and a technical appendix presents details on the decomposition of TFP.

2. PEG's TFP Specification

The EI Report makes some startling claims about PEG's TFP specification. Most importantly, they say that

> …much of the PEG (2009a,b) analysis is not appropriate because it attempts to treat energy distribution as if it were a competitive industry. The PEG analysis does not recognise the increasing returns to scale nature of the industry and the presence of sunk costs which means the 'indexing logic' PEG uses is inappropriate. It is precisely because of these features that the industry is being regulated.
>
> Large parts of the PEG reports on Economic Insights (2009a,b) are thus based on assessing the Economic Insights framework and key conclusions using the PEG framework which does not take proper account of important economic characteristics of energy distribution businesses. If one were to accept the PEG competitive industry framework as a starting point this may give the impression that many of the criticisms that are raised have some credibility but this is based on assuming a framework that does not take explicit or adequate account of the underlying economic characteristics of the industry under consideration.
>
> Furthermore, even if the PEG framework were accepted there are numerous problems in its interpretation and implementation (although many of these problems are not considered specifically here). In particular, the PEG TFP framework assumes that all capital invested in electricity distribution businesses is not sunk, ie it is variable and can be readily bought and sold in a competitive market and switched to alternative uses. The PEG TFP framework also does not make any explicit allowance for the scope for prices to reflect monopoly or market power related mark ups, ie output prices are assumed to be competitive.
>
> It is well recognised by Economic Insights that a focus of the approach to regulation in New Zealand and in many other jurisdictions is to try to regulate natural monopoly industries to mimic the outcomes that would arise in a 'workably' competitive market. However, there is a big difference in assuming a framework that relies on assumptions that a competitive market exists, as PEG does, and developing a framework that takes account of relevant characteristics not consistent with a competitive market in order to provide guidance on appropriate regulatory decisions to help achieve conditions consistent with a competitive market outcome, which is what Economic Insights (2009a,b) does.[18]

The Commission has apparently accepted these claims, and applied them more broadly to the "traditional" X factor formula. In the Draft Decisions Paper, the

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[18] Economic Insights (2009), *Electricity Distribution Productivity Analysis: 1996-2008*, p. 48.

Commission wrote that "the traditional formula is underpinned by a number of assumptions that are not relevant to EDBs – notably that the relevant markets are perfectly competitive and that capital is perfectly fungible."[19] EI advanced the claim about capital fungibility in its earlier reports, but its new claim that the traditional approach to TFP estimation for regulated industries (ironically) assumes that these industries are competitive was presented for the first time in this proceeding in the most recent EI Report.

These claims by EI are entirely incorrect. PEG's TFP specification relies on accounting *identities* which are true by definition. The 'indexing logic' results by applying straightforward algebra (and just a little calculus) to these accounting identities. Since the identities are true by definition, they are completely general and apply to an industry regardless of the degree of competition or whether it is characterized by constant or increasing returns to scale. PEG's derivation relies on just a single assumption, but this assumption applies to a *regulatory* objective, not the cost characteristics or state of competition in the industry. Moreover, this assumption is consistent with the Framework established in the Draft Decisions Report, and one which I believe the Commission will support.

It is easy to show mathematically that PEG's specification does not assume the industry is characterized by constant returns to scale or perfect competition in factor or product markets. I addressed the capital fungibility issue in my previous submission but will deal with it again in the following section. The analysis below simply reprises the indexing logic presented in PEG's earlier report, although it provides a bit more detail and rearranges the order of the equations to elucidate the relationships more clearly. However, it is mathematically equivalent to the "indexing logic" presented in my earlier reports.

I begin by noting that the cost of any industry (or enterprise) can be expressed as the product of an index of input prices (W) and an index of input quantities (X), as summarized in equation [1]:

$$C = W * X \qquad [1]$$

[19] Commerce Commission, *Draft Decisions Paper: Initial Reset of the Default Price Quality Path for Electricity Distribution Businesses*, p. 79.

It should be recognized that this expression applies to *any* industry, regardless of the degree of scale economies inherent in that industry's production technology. If we take logarithms of both sides of (1) and differentiate, we obtain the following expression

$$\Delta C = \Delta W + \Delta X \qquad [2]$$

Here the 'delta' symbol (Δ) refers to the rate of change of the variable in question with respect to time. Equation (2) has a straightforward and intuitive interpretation. It says that the rate of change in an industry's cost can be decomposed into two pieces: the change in the industry's input prices; plus the change in input quantities purchased by the industry.

We can also specify an index of output quantity *Y* for the industry. The rate of change of industry output quantity is therefore given by ΔY. If we subtract ΔY from both sides of [2] it is not changed. Doing so yields

$$\Delta C - \Delta Y = \Delta W + \Delta X - \Delta Y \qquad [3]$$

Dividing industry cost by the index of output quantity for the industry (*i.e. C/Y)* is defined as the industry's *unit* cost (*UC)*. The change in industry unit cost is therefore given by[20]

$$\Delta C - \Delta Y = \Delta U\mathrm{C} \qquad [4]$$

Similarly, industry TFP is defined as the index of industry output quantity divided by an index of industry input quantity (*TFP = Y/X)*. The change in industry TFP is therefore given by

$$\Delta Y - \Delta X = \Delta TFP \qquad [5]$$

If we substitute [4] in the left hand side of [3], and [5] in the right hand side of [3] and re-arrange terms, we have

$$\Delta U\mathrm{C} = \Delta W - \Delta TFP \qquad [6]$$

Equation [6] is simple but powerful result. It says that the rate of change in unit cost for an industry depends on the growth rate in industry input prices minus the growth rate of industry TFP. In other words, TFP is a *comprehensive* measure of *all* the factors that will lead the unit cost trend for an industry to differ from the trend in prices paid for

[20] Formally, this expression for the change in industry unit cost can also be obtained by taking logs and differentiating the expression (C/Y) = UC, as was done in moving from equation (1) to (2).

the inputs used in production. When TFP growth is positive, the TFP trend can therefore be interpreted as the amount by which the industry's unit cost trend has been kept below the trend in input prices confronting the industry.

Equation [6] has several important implications. First, it establishes a direct link between changes in TFP and changes in unit cost for an industry. Second, it shows that TFP is a comprehensive measure of all the factors that lead unit cost growth to differ from input price growth. It should also be recognized that this relationship is entirely general, and will therefore apply to industries that operate under increasing returns to scale technologies (which for utilities typically prevail over a large range of potential output).[21] If input prices and all other variables are equal, a realization of scale economies in an industry will by definition cause that industry's unit cost to decline. Equation [6] says that, when input prices are unchanged, a reduction in unit cost will be reflected in greater measured TFP growth. Thus under this basic indexing logic – which again leads directly to PEG's TFP specification – increasing returns are possible and, when they are realized, they will be captured in the TFP growth rate.

We now turn from cost to revenue. The revenue of any industry (or enterprise) can be expressed as the product of an index of output prices (*P*) and an index of output quantities (*Y*). Below we apply this identity to the regulated EDB industry.

$$R = P * Y \qquad [7]$$

Taking logarithms of both sides of (7) and differentiating yields

$$\Delta R = \Delta P + \Delta Y \qquad [8]$$

We can also define the change in margin in the EDB industry ΔM as follows

$$\Delta M = \Delta R - \Delta C \qquad [9]$$

Equation [9] is also entirely consistent with how EI has defined ΔM and how this term has been used in its indexing expressions. Since equation [9] applies to the regulated EDB industry, the ΔC term in [9] naturally applies to the regulated EDB industry as well. This is consistent with the analysis above which applies to all industries, and we can accordingly apply equations [1] – [6] into any further analysis that follows from [9].[22]

[21] The degree of scale economies in utility industries often varies depending on the amount of output, with relatively greater scale economies at lower output levels.

[22] More formally, the analysis that follows [9] is specific to the EDB industry and uses the EDB industry equivalents of [1]-[6], but the industry superscripts on variables are suppressed.

Now we come to the one and only assumption in our analysis. We assume that, in productivity-based regulation where a single X factor applies to the entire industry, the regulator wants to set allowed prices so that there is no change in margins for the EDB industry on average *i.e.* $\Delta M = 0$. From equation [9], it is clear that if $\Delta M = 0$ then

$$\Delta R = \Delta C \qquad [10]$$

If we subtract ΔY from both sides of [10] it is unchanged and yields

$$\Delta R - \Delta Y = \Delta C - \Delta Y \qquad [11]$$

From [8], we can see that $\Delta R - \Delta Y = \Delta P$; we substitute this in the left-hand side of [11]. We also substitute $\Delta UC = \Delta C - \Delta Y$ from [4] on the right-hand side of [11], and also substitute for ΔUC from [8] into the right-hand side of [11], which yields

$$\begin{aligned} \Delta P &= \Delta UC \\ &= \Delta W - \Delta TFP \end{aligned} \qquad [12]$$

This is of course the equation that links changes in output prices for the EDB industry to changes in industry input prices minus changes in industry TFP. If we assume that inflation will be measured by the CPI instead of directly by an industry input price index, further manipulation will lead to the "traditional" B factor formula that was used in the TFP thresholds regime. These further manipulations will have no impact on the appropriate industry TFP specification, which is the focus of the current exercise.

This simple analysis has some powerful implications (in addition to those discussed above). First, it focuses specifically on how TFP should be specified in a *regulatory* application for setting the rate of change in utility prices. The regulatory nature of this analysis is apparent in the assumption $\Delta M = 0$, or the regulatory objective that the rate of change formula should be calibrated to keep margins for the industry as a whole unchanged. This is the only assumption that appears anywhere in our analysis.[23]

[23] It may, however, be argued that there are two other implicit assumptions in our analysis. The first is that we are focusing on the industry TFP specification, and not TFP specifications for individual utilities. The second is that we are using historical observed trends to set allowed prices so that $\Delta M = 0$ rather than projected data on costs and outputs. However, both of these assumptions are explicit in the focus of the Commission's review, which sets a single X factor in the rate of change formula based on (but not necessarily equal to) achieved productivity growth. These assumptions in PEG's analysis are therefore clearly compatible with the Draft Decisions Paper.

This is also the only assumption that underlies the "competitive market paradigm" that was discussed in the earlier PEG papers. This is evident from the fact that when $\Delta M = 0$, the change in industry revenues equals the change in industry costs. The latter was assumed in the earlier papers, but since it is mathematically equivalent to $\Delta M = 0$ these assumptions are two sides of the same coin. Clearly, this assumption is motivated by the objective of deriving a rate of change formula that mimics the long-run outcome of competitive markets, where the change in industry margins is in fact equal to zero. Our analysis in no way "relies on assumptions that a competitive market exists," as EI asserts. It is no more valid to say that PEG's analysis assumes that the regulated industry is competitive than it would be to say that a regulator, acting as a surrogate for competitive market forces which are absent for regulated monopolies, transforms utilities into competitive industries. Such an argument confuses the analogy with reality.

I also believe the assumption that $\Delta M = 0$ is compatible with the Draft Decisions Report. In my opinion, this is evident in section 6.41, where the Commission says that it will undertake initial price adjustments on a business-specific basis so that costs are equal to revenues for all EDBs. The Commission notes that these price adjustments "would also mean that the final term (in Formula 6 of the Draft Decisions Report) relating to profits is not included (in the rate of change formula), just as the monopolistic mark-up term was not included in the Thresholds B-factor because profitability adjustments were implemented through the separate C_2 factor."[24] Thus, since the Commission will reset initial prices so that revenues equal costs for each EDB, the DPP will not target margins. Rather, the Commission will set the DPP so that the expected change in margins for the industry overall will be unchanged over the term of the DPP *i.e.* $\Delta M = 0$.

The assumption that $\Delta M = 0$ is also compatible with ex ante FCM. The TFP specification above is focused on satisfying the objective that the expected change in industry revenue over the term of the DPP equals the change in industry costs. This objective is furthered by the fact that PEG employs an ex post approach to capital measurement, which ensures that industry costs will equal revenues over the period for which TFP is measured.

[24] Commerce Commission, *op cit*, p. 75.

EI agrees that this is a feature of PEG's TFP specification, but not that it will lead to allocative efficiency or FCM. It writes "…PEG's (TFP) approach does ensure that industry revenues track costs but the industry costs may include excessive or deficient profits and would not therefore represent real opportunity costs. This feature of PEG's methodology…is not generally consistent with ensuring the principle of ex ante financial capital maintenance nor with achieving allocative efficiency in increasing returns industries."[25] In other words, EI agrees that our TFP specification ensures that industry revenues grow at the same rate as industry costs on an *ex ante* basis, but claims that this does not ensure FCM or allocative efficiency because there may be excessive or deficient profits at the outset. Since our rate of change formula fails to include terms that target such excess/deficient profits, EI claims they can be "locked in" under our approach.

This conclusion is flatly incompatible with the framework that the Commission adopted in the Draft Decision. Section 6.41 clearly states that the Commission will make initial price adjustments on a business specific basis to address any concerns it has in relation to individual profit levels. This process will ensure that any concerns in relation to profit levels are reflected in initial prices and therefore cannot be "locked in" by a rate of change formula where industry revenues necessarily track industry costs on an *ex ante* basis.[26] Moreover, throughout my work I assumed that the Commission would undertake such initial price adjustments before the rate of change formula took effect, since this occurs in nearly all productivity-based regulatory application for energy utilities and was expected here as well.

It should also be recognized that all features of PEG's TFP specification support the objective of having industry revenues track industry costs. This aim underpins my recommendation to use billing determinants as outputs and the use of (deflated) monetary rather than physical capital metrics. PEG's earlier reports provide an extensive

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[25] Economic Insights, *op cit*, p. 51.

[26] However, this rate of change formula will not ensure that margins are unchanged for every EDB over the term of the controls. This is not desirable public policy (*i.e.* such an approach will effectively destroy incentives to improve cost efficiency) and, even more fundamentally, cannot be achieved (except by chance) with a single X factor, which will be used for this initial Reset of the price controls.

discussion of why these features of our TFP specification are necessary for satisfying this goal, as well as how they flow logically from the indexing logic that is detailed above.

It bears repeating that PEG's TFP specification does not assume that the utility industry is competitive, nor that it is characterized by constant returns to scale, nor that the markets for the factors of production or the utility output is competitive. Equations [1] through [6] above capture the cost conditions of the industry and establish the link between changes in industry TFP and changes in industry unit cost. These equations are general identities that apply for any industry, regulated or competitive. The lion's share of EI's critique rests on the assertion that PEG assumes regulated industries exhibit the characteristics of competitive markets, and this claim is clearly and indisputably false. This does raise a question, however: how can a group of highly competent (even distinguished) regulatory economists come to such a fundamentally erroneous conclusion? The answer is revealing, since it helps to explain the entire analytical approach that EI has taken for this review.

3. THE FRAMEWORK FOR THE ECONOMIC INSIGHTS APPROACH

The EI analysis has attempted to embed TFP measurement for CPI-X regulation into economic theory. They are quite forthright about this approach, as the first paragraph of the EI report *The Theory of Network Regulation in the Presence of Sunk Costs* says "(t)he Commerce Commission has engaged Economic Insights Pty Ltd ('Economic Insights') to prepare a report which considers the interrelationship between the choice of asset valuation method and CPI–X price paths set using productivity analysis. To adequately address this topic it has been necessary to revisit the theory of regulation and fill in some important gaps which have existed to date."[27]

Readers familiar with this theory will recognize much of the EI analysis. Indeed, a key point of departure for EI is a literature of more than 50 years that focuses on integrating productivity into a more formal economic theory of production. Undoubtedly, few if any participants in this proceeding are familiar with this history (in fact, most Ph.D. economists are not familiar with this literature either; it is a specialized field within the profession). There would also be no reason to review this highly arcane topic except for two factors. One is that it has led EI to adopt a frame of reference that leads to significant errors, particularly the erroneous claims about PEG's TFP specification. Second, it leads EI to investigate theoretical puzzles that have no practical implications for regulatory applications of TFP measures.

Although the theoretical debates go back even further, the best starting point for understanding EI's approach is a Nobel Prize-winning paper published by Robert Solow in 1957.[28] This paper was titled "Technical Change and the Aggregate Production Function."[29] The purpose of the paper was "to isolate shifts of the aggregate production function from movements along it" (which, given the framework he developed and its application to macroeconomic data from the US, was equivalent to "segregating

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[27] Economic Insights, *The Theory of Network Regulation in the Presence of Sunk Costs*, Report prepared for Commerce Commission, p. 1.

[28] A good discussion of the research before the Solow paper, and Solow's contribution in integrating much of this work, is Z. Griliches (1996), "The Discovery of the Residual: A Historical Note," *Journal of Economic Literature*, Vol. 34, 1324-1330.

[29] Solow, R., (1957) "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics*, Vol. 39, 312-320.

variations in output per head due to technical change from those due to changes in the availability of capital per head.") In economic theory, "movements along the production function" correspond to changes in output that are associated with changes in input. "Shifts in the production function" are equivalent to technical change.

Solow's paper developed three different equations that can be used to isolate shifts in the production function from movements along the function. In retrospect, these equations are simple and straightforward, but regardless of their elegance Solow's paper represented an intellectual breakthrough. However, Solow was only able to derive these equations by making certain assumptions. In particular, he assumed that there were competitive markets for labor and capital services and, for two of the equations, he assumed a constant returns to scale technology.[30]

Solow showed that, when these conditions are satisfied, then a shift in the production function (*i.e.* technical change) will be equivalent to TFP growth (change in outputs in excess of change in inputs). Solow then applied his model to data on US economic output growth from 1909 to 1949. He estimated that only 12% of this growth in real output per man-hour was due to increased capital intensity, or greater capital inputs (per man-hour). The remaining 88% of real output growth was due to technical change.

Solow's paper inspired a large amount of subsequent work. Researchers noted that the technical change identified as being the main driver of real per capita output growth was in reality an unexplained "residual." Many therefore referred to technical change as the "Solow residual" and some even called it "the measure of our ignorance." Accordingly, there were efforts to undertake more accurate and detailed "growth accounting" in an effort to better explain the sources of economic and productivity growth which, under Solow's assumptions, was equivalent to technical change.

One of the seminal papers in this literature is "The Explanation of Productivity Change" by Dale Jorgensen and Zvi Griliches.[31] EI also references this paper, and states that this paper underpins our TFP specification. This reference also details some of EI's

[30] Solow also assumed what economists refer to as "neutral" technical change, which is an assumption that does not touch on the current debates and will not be discussed further.

[31] Jorgensen, D.W. and Z. Griliches, (1967) "The Explanation of Productivity Growth," *Review of Economic Studies*, Vol. 34., 249-283.

erroneous reasoning on why PEG's TFP specification assumes that the industry in question must operate under competitive market conditions. They write:

> Equation (4) on page 38 of PEG (2009a) is essentially based on the seminal work of Jorgenson and Griliches (1967) which shows that the primal and dual methods for calculating TFP growth coincide under certain conditions. In other words *Trend P– Trend W = – (Trend Y – Trend X) = – Trend TFP* is by definition only true when there is competitive price taking behaviour (where prices are equal to marginal cost) and constant returns to scale. For example, if there is not competitive price taking behaviour then equation (1) in PEG (2009a) which equates revenues and costs does not apply so one cannot arrive at (4). Similarly, if there are economies of scale equation (3) need not apply. In addition, the derivation of (3) requires competitive conditions to hold in the factor markets for all the firm's inputs: for example, the marginal cost of each input (including all capital inputs) is assumed to equal its market price in a competitive market in order to arrive at the share terms assumed in the equation. But clearly there is not a competitive market (nor a 'workably' competitive market) for sunk capital in the electricity distribution industry in New Zealand.[32]

However, it is very instructive to review what Jorgensen and Griliches actually say about the relationship between changes in measured TFP growth and the assumptions that EI identifies. Jorgensen and Griliches write:

> Our definition of changes in total factor productivity is the conventional one. The rate of growth of total factor productivity is defined as the difference between the rate of growth of real output and the rate of growth of real factor input. The rates of growth of real product and real factor input are defined, in turn, as the weighted averages of the rates of growth of individual products and factors. The weights are relative shares of each product in the value of total output and of each factor in the value of total input. *If a production function has constant returns to scale and if all marginal rates of substitution are equal to the corresponding price ratios, a change in total factor productivity may be identified with a shift in the production function. Changes in real product and real factor input not accompanied by a change in total factor productivity may be identified with movements along a production function*.[33] (emphasis added)

PEG's TFP specification is *identical* to what Jorgensen and Griliches call "the conventional one" [note that this conventional TFP specification includes relative shares of revenue (*i.e.* relative shares of each product in the value of total output) as output

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[32] Economic Insights, *op cit*, p. 49.

weights]. Moreover, Jorgensen and Griliches do **not** say that this conventional TFP specification requires competitive price taking behavior or constant returns to scale. On the contrary, the italicized text makes it clear that these assumptions are necessary **only** if the conventional TFP growth measure is to be identified with and equivalent to a shift in a theoretical production function.

This result is what EI refer to above when they say the "primal and dual methods for calculating TFP growth coincide (only) under certain conditions." A similar result was also evident in Solow's work, which was devoted to the specific purpose of distinguishing a shift in the production function from movements along the production function, which Jorgensen and Griliches clearly echo in the italicized text. But whether the "primal and dual methods for calculating TFP growth coincide" has no practical implications on estimating TFP growth to be used in a rate of change formula.[34] As Solow's work demonstrates, these assumptions come into play **only** when research goes beyond practical TFP measurement and embeds productivity in a formal economic theory of production. This theory can be useful for peeling back the layers of the onion and identifying more disaggregated sources of TFP growth, but it is entirely beside the point if the objective of the analysis is to develop a comprehensive estimate that necessarily reflects all sources of TFP growth.

This is in fact the measure of TFP growth that is required for CPI-X regulation. Recall the implications of the indexing logic that were discussed in the previous section. This logic showed that the TFP measure to be used in productivity-based regulation must be comprehensive and reflect all the factors that lead industry unit cost growth to differ from the growth in input prices facing the industry. The "conventional" TFP approach will produce this estimate of TFP growth and is therefore the appropriate method to use in practical regulatory applications.

The EI report is replete with references to the fact that the PEG TFP specification will not measure technical change because the assumptions necessary for TFP growth to

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[33] Jorgensen and Griliches, *op cit*, p. 250.

[34] There are limited exceptions to this rule, almost always pertaining to the case when X factors are to be "tailored" to the circumstances of individual utilities, but they do not apply in the current proceeding. This point is discussed further below.

be equivalent to a shift in the production function (for the "primary and dual methods for calculating TFP growth to coincide") are violated for regulated industries. For example:

> If there is marginal cost pricing, then $T^{*\prime}(t) = \tau(t)C(t)$; ie TFP growth is equal to technical change. This is just the dual expression of the usual Solow residual which is identified with technical change (an upward shift in the production function due to improving technology or equivalently, a downward shift in the cost function) and ***under the assumptions of competitive pricing and constant returns to scale, TFP growth is equal to technical change.*** However, if marginal cost pricing does not hold and there are not constant returns to scale, then conventionally defined TFP growth as defined by PEG (2009a) and PwC (2009) is not equal to technical change (pp. 58-59; bold in the original)

> …the new (*i.e.* EI) approach highlights important factors that contribute to TFP other than technical progress whereas the traditional (*i.e.* PEG) approach effectively defines TFP as technical progress which is incorrect for natural monopoly industries. The Economic Insights approach identifies those components of TFP growth other than technical progress. (p. 60)

Hopefully it is clear that EI's belief that PEG has defined TFP as being equivalent to technical change is not only incorrect, but the inverse of what we have done. PEG has intentionally used a TFP measure that includes all contributions to industry TFP growth. Restricting the industry "productivity" measure in productivity-based regulation to the industry's rate of technical change is not appropriate since this is only one component of TFP growth. EI's suggestion that "the traditional approach effectively defines TFP growth as technical progress" is also factually incorrect as a statement of how productivity-based regulation has been implemented. I am aware of more than 40 instances where information on TFP trends was used to set the terms of rate of change formulas, and in every one the "productivity" measure was not restricted to technical change.

The last quote from EI also emphasizes that there are components of TFP growth other than technical progress and says that one of benefits of its proposed "new" approach is that it identifies these components.[35] While I certainly concur with the view

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[35] This is evident from the sentences proceeding the statement quoted above, which was presented in the context of supposedly demonstrating that measured TFP growth under EI's methodology would be equivalent to TFP growth under PwC's proposed approach. EI wrote that "(h)owever, a question that may arise in the context of interpreting the algebraic example is that if the numerical estimate of TFP is the same under both approaches then why bother with the new

that TFP includes more than technical change, EI's identification of other contributions is not nearly as "new" as they suggest. Other papers in the economics literature have presented similar, although not identical, analyses which provide a framework for decomposing TFP into a variety of components. Indeed, PEG has undertaken such decompositions in our work for utility industries. We have also gone beyond these theoretical exercises and *estimated* the extent to which various factors contribute to TFP growth.

One of these studies was our 2004 analysis of TFP growth for the EDBs in Victoria, Australia, conducted on behalf of the Essential Services Commission of Victoria. The appendix to this submission presents the exact language in that report where we undertook a theoretical decomposition of TFP growth into six separate components. In addition to technical change (termed technological change in that report), these components include the realization of scale economies and the departure of prices from marginal costs, both of which EI explicitly says are neglected in our TFP estimates. PEG applied this equation to data from the Victorian EDBs, and we were able to obtain empirical estimates of some but not all of these factors to TFP growth in Victoria's electricity distribution industry.[36]

This Victorian study provides definitive proof that PEG's measured TFP growth is not equivalent to technical change (either conceptually or empirically). If the data were available, PEG could have implemented this same decomposition formula for the New Zealand EDBs and provided more information on the sources of industry TFP growth. However, there was no reason to do so since it was known that only a single X factor was to be applied to all EDBs. As we stated in our Victorian report (and in the appendix), TFP decompositions are typically desirable in productivity-based regulation only if X factors are to be "tailored to utility circumstances that differ materially from industry norms (either historically or at a given point in time). This can be done by

approach. There are two answers to this. The first is that the new approach highlights important factors that contribute to TFP other than technical progress whereas the traditional approach effectively defines TFP as technical progress which is incorrect for natural monopoly industries. The Economic Insights approach identifies those components of TFP growth other than technical progress."

[36] In particular, it was not possible to distinguish the inefficiency factor from technological change, or quantify the impact of non-marginal cost pricing, due to lack of data.

developing information on the sources of TFP growth and adjusting the X factor to reflect the impact on TFP resulting from differences between a utility's particular circumstances and what is reflected in historical TFP trends." Since a single X factor was to be applied for the rate of change formula, there was no reason to use econometric methods to decompose TFP growth into different components in order to develop company-specific, "tailored" X factors. Ironically, even though EI claims that its TFP framework is superior to PEG's, its decomposition of TFP growth (unlike PEG's) is entirely theoretical and was not practically implemented. Thus EI's analysis would not lead to any practical benefit in this review even if the Commission was interested in developing multiple, tailored X factors.[37]

In sum, EI's belief that PEG's TFP specification assumes that the EDB industry is competitive and characterized by constant returns to scale is entirely a strawman of its own construction. EI was apparently driven to this erroneous conclusion because the frame of reference it adopted for its work was entirely theoretical rather than practical. EI's analysis is firmly rooted in the "growth accounting" theoretical literature which (going back to Solow's 1957 paper) *begins* by making the assumptions necessary for TFP growth to be equivalent to technical change, then progressively relaxes those assumptions in order to identify the various contributors to TFP (and in macroeconomic applications, economic) growth. EI apparently believed that PEG adopted the same perspective, but in fact we began from the opposite vantage point and developed a TFP specification that necessarily includes all potential contributions to TFP growth. We could have adopted a more complex analytical framework that decomposed TFP growth into different components, as EI did, but there was absolutely no reason to do so since a single X factor was to be applied to all the EDBs and this X factor should reflect all the contributions to industry TFP growth.

[37] Another irony is that at least some EI personnel were very familiar with PEG's TFP work in Victoria and the decomposition of TFP undertaken there. In fact, a similar decomposition of partial factor productivity growth for operating inputs into an identical set of contributors (plus an additional factor reflecting the impact of capital stock) was described by EI personnel as "well grounded in economic theory;" see Meyrick and Associates (2007), *Gas Distribution Opex Rate of Change*, Report to the Victorian Gas Distribution Businesses, p. 3. It should therefore have been clear that PEG neither assumes that TFP is equivalent to technical change, nor that PEG's TFP estimates include only technical change.

Finally, I believe this historical overview may shed light on the discussion of EI's views on capital fungibility that appeared in my previous submission. This discussion appears in section 4.2.1.4 of the submission, and below I replicate the sections that pertain most directly to this issue (note: this quote is lengthy, but it is difficult to excerpt this discussion without losing valuable context):

> …. Christensen and Jorgensen are drawing a *distinction* between two different options for measuring capital inputs and service prices. One uses direct, market-based rental rates that result from transactions when capital is freely tradable. The other is the ex ante cost of capital measure, which results from an imputation based on the discounted value of the capital services. The authors pose these as *different* approaches towards estimating capital cost; clearly, the ex ante second option does not depend on, or otherwise assume, that assets are freely variable as in the first approach. The Christensen and Jorgensen discussion of the ex ante approach therefore contrasts sharply with the EI exposition, which claims that only "in this freely variable case, the purchase price can be decomposed into a sum of discounted period by period rental prices or user costs…in the case of irreversible or sunk cost investments, the argument in the previous sentence does not work." Christensen and Jorgensen say otherwise; they note that "factor outlay on capital may be separated (i.e. decomposed) into price and quantity components" in their approach, which they must undertake because capital is *not* freely tradable, not because it is.
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> This discussion shows that we do not need to assume that capital is freely variable for practical measurement (using the ex ante, Jorgensen measure) of the costs of sunk assets. These capital cost measures can, in turn, be used as components of TFP studies, including TFP studies for electricity distribution networks. While we do not agree with EI's statements regarding the need to assume freely variable capital to measure sunk costs, we do believe they are making a more valid point in another context. That context, however, is one of almost pure economic theory rather than practical utility regulation.
>
> This can be seen by considering two equations that appear in the Theoretical Report. The first is equation (157), which is obtained in the freely variable capital case when the cost function is differentiated with respect to capital.
>
> (157) $P_k = -\partial c(y,w,k)/\partial k$
>
> The right hand side is the differential of the cost function with respect to capital; the left hand side is the price of (imported) capital. Compare this with equation (219) where capital is sunk and cannot be varied.
>
> (219) $P_k = -\partial c^1(y^1,w^1,k)/\partial k - \partial c^2(y^2,w^2,k)/\partial k$;

EI compares these equations, and considers their implications, in an illuminating discussion on page 55:

> Recall equation (219) in the previous section, which set P_k, the purchase price of a new unit of capital, which when installed or built cannot be varied for its useful life, equal to $-\partial c^1(y^1,w^1,k)/\partial k \geq 0$ (which is the marginal user benefit that this fixed capital stock will generate in period 1) plus $-\partial c^2(y^2,w^2,k)/\partial k \geq 0$ (which is the marginal user benefit that this capital stock will generate in period 2). These partial derivatives of the opex cost functions play a crucial role in the determination of the rate of opex technical progress as we saw in section 5.4 above; ie recall equation (157) in section 5.4. However, in section 5.4, because we assumed that the capital input was variable, we could argue that the derivative $-\partial c^1(y^1,w^1,k)/\partial k$ could be closely approximated by its observable user cost. In the present context, we cannot make the same argument due to the fixity of the capital. This fact creates problems for the measurement of technical progress.[38]

The entire focus of EI's discussion here is on the *interpretation* of a derivative. When capital is freely variable, the derivative of cost with respect to capital can be interpreted as, and "closely approximated by, its observable user cost." However, when capital is sunk, "we cannot make the same argument due to the fixity of capital." In this circumstance, "the purchase price of a new unit of capital, which when installed or built cannot be varied for its useful life" will be equal to the sum of its marginal user benefits (*i.e.* the sum of opex cost savings in periods one and two that result from this fixed cost investment). The issue of freely variable vs. sunk capital costs is therefore not, in a practical sense, whether their capital service prices and service flows can be measured using "standard" techniques; in both cases, they can. EI is instead investigating how these different capital assumptions relate to the theoretical cost function; the implications for how to define and categorize firms' optimizing behavior with respect to capital inputs; and the corresponding decomposition of TFP growth into distinct components.

If this seems like an exceptionally arcane topic, it has actually received a fair amount of attention in the economics literature. Ever since Solow's pioneering work in the late 1950s, economists have debated the extent to which TFP growth can be interpreted as a shift in the cost function. This is equivalent to evaluating the extent to which measured TFP growth is equivalent to technical progress. It has been established that technical change is only one component of TFP growth, and TFP growth will be equivalent to technical change only when certain assumptions are satisfied. As the passage above indicates, measuring

[38] Economic Insights (2009a), p. 55.

technical progress is also central to EI's analysis.

> However, the extent to which TFP can be interpreted as technical progress, and the degree to which this divergence depends on the fixity of the capital stock, are not issues that have any practical relevance for setting the terms of the DPP. Capital costs can be and have been estimated in multiple TFP studies for energy networks, as well as other industries (such as telecom, railroads and oil pipelines) that have "sunk" assets. The sunk nature of many EDB assets is therefore not a barrier to practical TFP measurement in this proceeding (even using the "standard" ex ante cost of capital approach that PEG is not recommending). EI's Theoretical Report may have much to offer the academic specializing in productivity measurement, but it should be seen as a contribution to a long line of theoretical literature rather than an identification and potential remedy for problems inherent in using "standard" measures of TFP growth in CPI – X regulation.[39]

Perhaps this discussion would have been clarified by explicitly referencing the theoretical literature, beginning with Solow's 1957 paper, that EI was building on and responding to. I was trying to avoid unnecessary digressions into purely theoretical or historical topics, but EI's latest claims have made it necessary to understand how this theory has led to misinterpretations of PEG's TFP specification. This theoretical review has also made it possible to distill the essence of the argument above, hopefully more clearly.

To simplify just a bit, EI's concerns regarding capital fungibility essentially stem from the fact that Solow's 1957 paper (and some subsequent work) assumes perfectly competitive markets for capital services.[40] A perfectly competitive market cannot exist for the *entire* capital stock of an enterprise because some capital assets are 'sunk' and therefore cannot be varied in response to changes in capital user prices. EI therefore contends that "conventional" TFP measures assume that capital markets are perfectly fungible or, in their words, "the PEG TFP framework assumes that all capital invested in electricity distribution businesses is not sunk, ie it is variable and can be readily bought and sold in a competitive market and switched to alternative uses" (p. 48).

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[39] PEG submission , pp. 46-48.

[40] This assumption is necessary for capital to be paid its marginal product, which in turn is necessary to simplify Solow's initial differentiation of the production function. An equation that is very similar to equation (157), referenced in the preceding quotation from EI's Theoretical report, is therefore implicit in Solow's original analysis.

However, this claim is incorrect. The reason is that the assumption that EI finds objectionable is only invoked in *theoretical* work that attempts to embed productivity into formal economic models. More precisely, when EI says (p. 49) "the marginal cost of each input (including all capital inputs) is assumed to equal its market price in a competitive market in order to arrive at the share terms assumed in the (cost) equation," this statement is not true with reference to developing index-based measures of input quantity, which are the metrics used directly in empirical TFP studies and, hence, the X factor in the rate of change formula. These index-based metrics are computed using data that do not depend either implicitly or explicitly on marginal costs, so there is no need to invoke the price = marginal cost assumption. This assumption is only necessary when researchers attempt to link productivity measures to the *theoretical* cost function. This relationship assumes optimizing behavior by firms, which in a theoretical context will mathematically take effect by differentiating the cost function with respect to individual inputs. The optimal choice for each input (including capital) is then determined by solving for the value where this derivative is equal to zero. The derivative of cost with respect to an input is the marginal cost that EI refers to above. But again, the derivation of this marginal cost occurs only in the theoretical realm of the production function; it plays no role either explicitly or implicitly in the index-based measurement of capital costs or input quantities developed by PEG in this proceeding. Since this assumption plays no role whatsoever in measuring the price or quantity of capital services in "conventional" TFP estimation, EI's entire discussion of capital fungibility applies to puzzles that exist only at the theoretical level but have no practical implications for TFP measurement.[41]

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[41] An analogy from the field of physics might be the relationship between quantum mechanics, which describe the behavior of very small particles, and general relativity, which describes the relationship between time, space and gravity. Some theoretical implications of quantum mechanics contradict the implications of general relativity, yet physicists agree that both are true when applied to the realms for which they were developed. If a group of scientists – say those working at NASA in 1961 – were given the task of putting a man on the moon before the decade was over, their time would be better spent by addressing the practical challenges that confront them, using the appropriate tools and models, rather than attempting to resolve the theoretical discrepancies that exist below the surface and at a very deep level with the field. Indeed, physicists have attempted to develop such a "unified field theory" for about 80 years and still have not agreed on one. EI has attempted a variant of a unified field theory of regulation in this proceeding, but this effort was focused on theoretical puzzles rather than issues that play any concrete, practical role in TFP measurement.

In closing this section, I should emphasize that none of these remarks are meant to disparage EI's work. This work is impressive on a theoretical level and intriguing for a productivity specialist. Unfortunately, it is motivated by theoretical concerns rather than practical TFP measurement issues that need to be addressed. This approach was not fit for the purpose of this review. In fact, the EI framework has fostered confusion and led to significant misinterpretations rather than enhanced clarity and understanding of the relationship between unit costs, TFP and the rate of change in utility prices. EI may disagree with our TFP specification for other reasons, but they cannot in good faith continue to maintain that PEG's TFP specification assumes that the EDB industry exhibits the characteristics of a competitive market. This is such a serious and fundamental error that, in the interests of developing a full, accurate and transparent record for future proceedings, I believe it should be acknowledged and rectified in the Final Decision.

4. IMPLICATIONS OF ECONOMIC INSIGHTS SPECIFICATION

There has already been extensive debate on the extent to which the EI and PEG TFP specifications satisfy the criteria that the Commission established for this review. I do not want to rehash this debate but do believe it is important to respond to claims that EI has made about two specific issues. The first is alternative capital measures and their ability to reflect capital replacement expenditures. The second is the relationship between changes in revenues and outputs choices in the TFP specification. I deal with each of these issues in turn.

4.1 Capital Replacement and the Choice of Capital Measures

Both the Commission and the EDBs largely agree that capital replacement expenditures are accelerating in the industry (although they differ on the magnitude). Compared with the observed past, if there are greater capital replacement expenditures in the industry, there will be greater growth in the real (*i.e.* inflation-adjusted) unit cost of distribution service. This should be reflected in greater increases in allowed, real distribution prices to recover these higher unit costs. Real price increases are equivalent to a reduction in the X factor (again, compared with what was approved in the past). Furthermore, because these unit cost pressures stem from industry pressures, they should be reflected in either the industry TFP trend or industry input price trend components of the X factor (*i.e.* the impact of increased replacement of EDB assets on economy-wide TFP or input price growth will be negligible or nil).

One of the practical benefits of using (deflated) monetary values rather than physical metrics to measure capital is that they reflect the impact of capital replacement expenditure on industry unit costs more directly and transparently than physical capital metrics. Since the change in unit cost is equal to the change input prices minus the growth in TFP, a higher volume of capital replacement expenditures (as opposed to an increase in capital asset prices) will necessarily be reflected in a lower measured TFP growth rate. This will, in turn, lead to a lower X factor and greater allowed changes in prices to recover these higher unit costs.

The reason that monetary values reflect the impact of capital replacement expenditures on unit cost growth, and measured TFP growth, more directly than physical metrics is intuitive. When capital is measured by physical counts, the replacement of one asset by another does not impact the physical amount of assets in the system. The change in measured input quantity is therefore zero. All else equal, capital replacement therefore has no impact on measured input quantity growth, measured TFP growth or the X factor.

This is not the case when monetary values are used to measure capital. The monetary value of the replacement capital added to the system almost always exceeds the value of the asset being replaced. Some of this extra cost will no doubt be due to the inflation in capital asset prices that has occurred over the replacement cycle. In addition, new assets can also be more expensive because they are of higher quality. Improvements in asset quality should be reflected in changes in the quantity of assets that are employed, since the utility now effectively has "more" of an asset available for production. Because the costs or replacement assets are greater, a monetary valuation of capital will typically lead to an increase in the amount of measured capital input, which all else equal leads to a reduction in TFP growth and a higher X factor. This contrasts with the use of physical metrics where, as in the example above, replacement expenditures have no impact on the X factor. A higher X factor is appropriate to recover the increase in the EDB's unit cost.

There is also evidence of this phenomenon in the TFP studies presented by PEG and EI in this proceeding. Below I present data on growth in capital inputs for 2004-2008. This is the period over which capital replacement is widely believed to be accelerating (such an acceleration is also supported by empirical evidence from PEG's study). EI does not present any data on comprehensive capital input, but it does present information on PFP growth for overhead lines, underground cables, and transformers (Table 1 in the EI Report). I use these PFP estimates, along with the reported growth in EI's output quantity index, to compute growth in input quantity for overhead (OH), underground (UG) and transformer (Transf) assets over the 2004-2008 period, using the identity that capital input quantity growth = output quantity growth – capital PFP growth. I also develop an estimate of total capital input quantity growth using cost share weights based on information on the user cost of OH, UG, and Transf assets presented in EI's Table A1 in Appendix A. The results are presented below.

NZ EDBs' Growth in Capital Input, 2004-2008

	Total Capital Quantity	OH	UG	Transf
PEG	3.10%			
EI	1.95%	0.66%	2.51%	2.50%

I also computed alternative quantity estimates using the direct capital measures reported for OH, UG and Transf assets in Appendix A. The latter OH and Transf quantity estimates were the same as those reported above, but for some reason the growth in UG assets was smaller in the latter approach (1.96% versus 2.51%); if the latter value is correct, then EI's average increase in total capital input quantity over the 2004-2008 would be 1.76%. In either case, it can be seen that PEG's monetary value of the EDBs capital stock grows more rapidly than EI's physical measure of this capital stock. This is consistent with the fact that PEG's measure is capturing the additional capital input, and upward pressure on EDB unit costs, stemming from accelerated capital replacement expenditures, but EI is not. If all of the differential estimated above was due to capital replacement, and capital accounted for about 60% of costs, then an appropriate adjustment of the X factor for the EDBS developed with physical capital metrics would be approximately -0.7% (*i.e.* (1.95%-3.10%)*.6 = -0.69%).

Finally, it should be reiterated that the issue of physical versus monetary capital metrics was debated extensively in the 2008 Ontario incentive regulation proceeding, and the regulator strongly rejected the use of physical capital metrics. EI says that this claim is "incorrect" and contends that

> "the major problem with the Ontario estimates was that there were no data for the period 1998 to 2002 and data prior to 1998 was not available on the same basis as the recent data. The regulator was concerned that a 'patchwork' approach would have to be adopted that involved different approaches to capital measurement (given that the original Ontario study covering the period up to 1997 had used a 'monetary' approach). There was thus no 'extensive' or independent evaluation of the merits of the two approaches in this proceeding. It should be noted that the Ontario regulator also rejected some aspects of its own advisor's analysis (Ontario Energy Board 2008, p.12)."[42]

[42] Economic Insights, *op cit*, p. 67.

This characterization of the Ontario proceeding is plainly incompatible with the Ontario Energy Board's final decision, which states:

> The Board accepts the use of U.S. data for the purposes of the derivation of the TFP trend for 3rd Generation IR. Use of this data set was supported by PEG and Prof. Yatchew. Ms. Frayer (representing the team that included EI personnel) sought to circumvent the problem through a patchwork of studies that, in the Board's view, are not adequately demonstrated to be based on a series of consistent principles. *Of greatest concern with Ms. Frayer's approach is the measurement of capital, which is inconsistent with the prior Ontario TFP studies and does not appear to have been adopted in any jurisdiction other than New Zealand* (italics added)[43]

It can be seen that the Board does express concern with the "patchwork" approach that London Economics and EI personnel promoted, but contrary to EI's claim it did not conclude that this was "the major problem" with the study. Instead, the Board's "greatest concern" was with the proposed *measurement* of capital, which they explicitly linked to how capital was measured in the TFP study presented in New Zealand. The Board also noted that this approach to capital measurement has not been adopted in any other productivity-based regulation plan, a clear reference to the use of physical capital measures which have, in fact, apparently been adopted only a single time in TFP studies for regulatory applications. EI may disagree with the Board's reasoning, but they cannot dispute that the Board singled out the proposed physical capital measures as their "greatest concern" which led to the rejection of the TFP study supported by EI personnel.

EI also mischaracterizes the nature of the review process in Ontario. The Board members evaluate all proposals before them on an equal, objective basis. This includes the proposal I put forward as an advisor to the Staff of the OEB. There were five days of debate before Board members on a wide variety of incentive regulation topics, and it is clear from the transcripts from that most questions were directed towards me. This is appropriate and not surprising, since the Staff's proposal was the first presented in the proceeding and proposals from other stakeholders were offered in response to the Staff's position. It is also clear from the transcripts that the issue of how to measure capital in TFP studies received a significant amount of attention in the proceedings.[44]

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43 Ontario Energy Board, *Supplemental Report of the Board*, September 17, 2008, p. 12.

44 For example, see pp. 55-61 and 67-75 of the transcripts from the March 27, 2008 stakeholder meeting; pp. 76-92 of the transcripts from the August 5, 2008 meetings; and pp. 17-20 and 31-33 in the August 6, 2008 meetings.

Board members consider all the evidence and proposals before them impartially. Indeed, in the first incentive regulation plan that was approved by the OEB in January 2000, they rejected the proposal of the Staff's advisors and crafted their own plan.[45] In 2008, however, the Board adopted every aspect of my output quantity specification, input quantity specification and TFP estimates for the rate of change formula; the *only* aspect of my TFP recommendation that the OEB "rejected" was the period for which TFP was to be measured. I recommended an 11-year sample period (1995-2006), but the Board selected an 18-year sample period (1988-2006).

4.2 Changes in Revenues and the Choice of the Output Measures

Another issue that was discussed in the EI Report and the Draft Decisions Paper was the choice of output measures and how these choices impacted the subsequent alignment of changes in revenues with changes in costs during the term of the price controls. PwC supported and expanded on the position put forward in my submission, that the correct outputs for this purpose are the billing determinants. PwC wrote:

> 'It is submitted that the question of what definition of output is 'right' for regulatory purposes is not the definition that reflects 'exactly what service does an energy distribution business provide' or the service that reflects best the utility gained by customers. Rather the right definition of output is the one that is most likely to generate a price path that aligns an EDB's revenue stream with its costs (that is, achieves ex ante financial capital maintenance). Assessed against this objective, it seems self evident that using a measure of output that does not reflect how prices are set can lead to obvious errors (that is even if there is only one regulated firm). This argument is explained most simply by providing a simple example, which is set out in Box 1 below.'[46]

EI responded to PwC's numerical example by saying (p. 53)

> "(t)his example does not, however, reflect the proposal in the Economic Insights (2009a,b) reports. The PwC example is an interpretation of the way that TFP has been traditionally implemented to date but with the substitution of an output measure that does not have a market price. But the Economic Insights approach does not entail the exclusive use of an 'abstract' output measure with no market price. Thus, the simple PwC example is neither relevant nor reflective of the Economic Insights approach.

[45] Some EI personnel apparently were part of the team advising the OEB for the first generation incentive regulation plan.

[46] Economic Insights, *op cit*, pp. 52-53.

> To demonstrate that the PwC example does not interpret our approach correctly, an example is presented below to show that the Economic Insights methodology does derive a price increase which ensures revenue aligns with cost. We do this in a simplified framework that uses the same basic data as presented in the PwC example[5]. The point is that although some outputs included in the calculation of TFP may not be priced, the price of those outputs that do have a market price must increase sufficiently to ensure revenues align with costs.

EI then re-expresses the PwC example using their notation and shows that it leads to a 13.9% increase in the price of Q_1, which is very similar to PwC's estimated 14 per cent increase. EI then writes (p. 54) "(t)o show the consistency of the Economic Insights methodology in arriving at the estimated price increase of 13.9 per cent it is necessary to develop the counterpart to equation (278) in the Economic Insights (2009b) technical report. This equation requires estimates of the rate of technical progress and estimates of marginal costs and this information was not presented in the PwC example."

However, not only were "estimates of the rate of technical progress and estimates of marginal costs…not presented in the PwC example," this information was never presented or used to develop EI's output quantity index either. EI's "demonstration" of the equivalence of their method and the PwC result is similarly unmoored from the actual methodology that EI used to estimate output growth. This demonstration first assumes an econometric cost function that never appeared in their TFP work, followed by an assumed number of quantitative values of cost function parameters that were never estimated, followed by a series of algebraic manipulations that were never undertaken. The end result of this process demonstrates nothing about EI's method, because the demonstration does not replicate the approach that EI used to estimate output growth. It is also not sufficient to say that EI's example could have been implemented, or represents an equivalent representation of their index-based approach. An econometric approach to estimating TFP would require far more data than index-based methods, would have dramatically increased the complexity of the process, and certainly may not have yielded the parameter estimates that EI assumes. PwC's example therefore stands unrebutted, and the intuition underlying their analysis and ultimate conclusion are both correct.

EI also provides what it calls "a concrete example" of the implications of using PEG's proposed output specification. They write (p. 59):

> It may be helpful to provide a concrete example of the distortions that can arise from using simple revenue weights and billable outputs to form an estimate of TFP growth that could be used in setting an X factor. The Australian states of Victoria and Queensland have diametrically opposed charging practices. In Victoria the EDBs place the majority of their charges on the variable components of throughput and, to a lesser extent, peak demand. In Queensland, on the other hand, EDBs place nearly all their charges on fixed components, ie there are negligible throughput and peak demand charges. Throughput has been growing faster than customer numbers in recent years. If billable outputs and revenue weights were used to form the average TFP growth rate across these two states and a common price cap applied based on this then the resulting estimate would be appropriate for none of the EDBs. This is because the output weights used to form the average industry TFP estimate would reflect to any meaningful extent neither the pricing nor the underlying costs of any of the EDBs given the diametrically opposed charging practices of the two states. If the alternative approach of using functional (or economic) outputs (of which billable outputs are a subset) and allowing for both costs and prices in forming output weights is used, then all EDBs are put on an even footing and the resulting TFP estimate will be more appropriate for use in setting a common X factor across all the EDBs

I agree that if two companies differ in terms of the relative revenues collected from two outputs, and those outputs grow at different rates, the revenues for these companies will grow at different rates. PEG's specification would lead to average revenue (and margin) growth that therefore differs from the revenue (and margin) growth for either of the companies. But this result stems entirely from the fact that a single X factor is being applied to the entire industry, so it is impossible to tailor the value of X to be specific to individual company circumstances (which would be a difficult and contentious exercise to attempt).

EI's "functional output" does not solve this problem any more effectively than PEG's. Companies would still start with differences in rate designs and experience different rates of output growth, which would lead to the same outcome of having different rates of revenue and margin growth. If a non-priced "functional" output is added to the TFP specification, the only effect will be to drive a wedge between revenue and cost growth for the industry as a whole (unlike PEG's approach, where industry revenues and costs grow at the same right), while doing nothing to correct the "problem" for individual companies.

EI's analysis therefore never demonstrates that including unbilled outputs in the output specification ensures that "all EDBs are put on an even footing." This can only be achieved in theory through a more complex, tailored set of X factors, including X factors that includes company-specific adjustments for the differences between prices and marginal costs by output. EI's approach clearly does not include these adjustments, and developing the required marginal cost information would prove costly, contentious and (almost certainly) unsuccessful given the complexity and data requirements of the exercise.

5. Concluding Comments

In conclusion, I remark briefly on the issues of complexity and relevance. It is true that any estimation of industry TFP and input prices will involve a certain "irreducible" level of complexity, but there is no reason to make this exercise more complex than necessary. I believe EI's approach, while interesting to the specialist, simply was not necessary or appropriate for this review. It was motivated by a desire to burrow into the finer points of the economic theory of production and its potential application to utility regulation. However, the "sunk cost" issues that occupy so much of EI's analysis are puzzles that exist only at the theoretical level and not on the more practical plane of TFP measurement. This theoretical frame of reference also led EI to misinterpret and mischaracterize PEG's TFP specification.

I also believe that, if the Commission continues down this path, the EDBs and customer groups will literally never understand the rationale for how their prices are adjusted under the rate of change formula. Frankly, it's not reasonable to ask them to try. The EI analysis presupposes a level of expertise that will limit the accessibility of their work to a relatively small number of specialists.

Time constraints probably prevent an immediate resolution of these debates. Nevertheless, I urge the Commission to carefully consider the logic and implications of the TFP specification that I have recommended on behalf of the ENA. I believe that close inspection will satisfy the Commission that it does not suffer from the defects that EI claims, for if it did it would never have been approved by regulators of a diverse set of network industries. I also believe it represents a more transparent and sustainable foundation for effective incentive regulation of New Zealand EDBs, which is why I have recommended that it be adopted in this proceeding.

APPENDIX: THE SOURCES OF TFP GROWTH

(*Note: this decomposition of TFP growth into various components first appeared on pp. 99-102 of the December 2004 PEG report "TFP Research for Victoria's Power Distribution Industry," prepared for the Essential Services Commission of Victoria Australia. A full copy of this report is available at the ESC website or by request from the author*).

There are rigorous ways to set X factors so that they are tailored to utility circumstances that differ materially from industry norms (either historically or at a given point in time). This can be done by developing information on the sources of TFP growth and adjusting the X factor to reflect the impact on TFP resulting from differences between a utility's particular circumstances and what is reflected in historical TFP trends. To provide a conceptual foundation for such adjustments, below we consider how the broad TFP aggregate discussed above can be decomposed into various sources of productivity change.

Our analysis begins by assuming a firm's cost level is the product of the minimum attainable cost level C^* and a term η that may be called the inefficiency factor.

$$C = C^* \cdot \eta . \qquad [9]$$

The inefficiency factor takes a value greater than or equal to 1 and indicates how high the firm's actual costs are above the minimum attainable level.[47]

Minimum attainable cost is a function of the firm's output levels, the prices paid for production inputs, and business conditions beyond the control of management. Let the vectors of input prices facing a utility, output quantities and business conditions be given by $\boldsymbol{W}$ $(= W_1, W_2 \ldots W_J)$, $\boldsymbol{Y}$ $(= Y_1, Y_2 \ldots Y_I)$, and $\boldsymbol{Z}$ $(= Z_1, Z_2 \ldots Z_N)$, respectively. We also

[47] A firm that has attained the minimum possible cost has no inefficiency and an inefficiency factor equal to 1. The natural logarithm of 1 is zero, so if a firm is operating at minimum cost, the inefficiency factor drops out of the analysis that follows.

include a trend variable (*T*) that allows the cost function to shift over time due to technological change. The cost function can then be represented mathematically as

$$C^* = g(\mathbf{W}, \mathbf{Y}, \mathbf{Z}, T). \qquad [10]$$

Taking logarithms and totally differentiating Equation [2] with respect to time yields

$$\dot{C} = \left(\sum_i \varepsilon_{Y_i} \cdot \dot{Y} + \sum_j \varepsilon_{W_j} \cdot \dot{W} + \sum_n \varepsilon_{Z_n} \cdot \dot{Z} \right) + \dot{g}. \qquad [11]$$

Equations [9] and [11] imply that the growth rate of *actual* (not minimum) cost is given by

$$\dot{C} = \left(\sum_i \varepsilon_{Y_i} \cdot \dot{Y} + \sum_j \varepsilon_{W_j} \cdot \dot{W} + \sum_n \varepsilon_{Z_n} \cdot \dot{Z} \right) + \dot{g} + \dot{\eta}. \qquad [12]$$

The term ε_{Y_i} in equation [4] is the elasticity of cost with respect to output i. It measures the percentage change in cost due to a small percentage change in the output. The other ε terms have analogous definitions. The growth rate of each output quantity i is denoted by $\dot{Y}$. The growth rates of input prices and the other business condition variables are denoted analogously.

Shephard's lemma holds that the derivative of minimum cost with respect to the price of an input is the optimal input quantity. The elasticity of minimum cost with respect to the price of each input *j* can then be shown to equal the optimal share of that input in minimum cost (SC_j^*). Equation [11] may therefore be rewritten as

$$\begin{aligned} \dot{C} &= \sum_i \varepsilon_{Y_i} \cdot \dot{Y} + \sum_j SC_j^* \cdot \dot{W} + \sum_n \varepsilon_{Z_n} \cdot \dot{Z} + \dot{g} + \dot{\eta}. \\ &= \sum_i \varepsilon_{Y_i} \cdot \dot{Y} + \dot{W}^* + \sum_n \varepsilon_{Z_n} \cdot \dot{Z} + \dot{g} + \dot{\eta}. \end{aligned} \qquad [13]$$

The W^* term above is the growth rate of an input price index, computed as a weighted average of the growth rates in the price subindexes for each input category. The *optimal* (cost-minimizing) cost shares serve as weights. We will call W^* the optimal input price index.

Recall from the indexing logic presented earlier that

$$T\dot{F}P = \dot{Y} - \dot{X} \qquad [14]$$

And

$$\dot{X} = \dot{C} - \dot{W} \qquad [15]$$

The input price index above is weighted using actual rather than optimal cost shares. Substituting equations [14] and [15] into [13], it follows that

$$\begin{aligned}
T\dot{F}P &= \dot{Y} - \left(\dot{C} - \dot{W}\right) \\
&= \dot{Y} - \left[\left(\sum_i \varepsilon_{Y_i} \cdot \dot{Y}_i + \sum_n \varepsilon_{Z_n} \cdot \dot{Z}_n + W^* + \dot{g} + \dot{\eta}\right) - \dot{W}\right] \\
&= \dot{Y} - \left[\left\{\left[\left(1 - \frac{1}{\sum \varepsilon_{Y_i}}\right) \cdot \sum \varepsilon_{Y_i} \cdot \dot{Y}_i + \sum_i \frac{\varepsilon_{Y_i}}{\sum_i \varepsilon_{Y_i}} \cdot \dot{Y}_i\right] + \sum_n \varepsilon_{\dot{Z}_n} \cdot \dot{Z}_n + W^* + \dot{g} + \dot{\eta}\right\} - \dot{W}\right] \\
&= \dot{Y} - \left\{\left[\left(\frac{1}{\sum \varepsilon_{Y_i}} - 1\right) \cdot \sum \varepsilon_{Y_i} \cdot \dot{Y}_i + \dot{Y}^{\varepsilon} + \sum_n \varepsilon_{\dot{Z}_n} \cdot \dot{Z}_n + W^* + \dot{g} + \dot{\eta}\right] - \dot{W}\right\} \\
&= \cdot\left(1 - \sum \varepsilon_{Y_i}\right) \cdot \dot{Y}_i + \left(\dot{Y} - \dot{Y}^{\varepsilon}\right) + \left(\dot{W}^* - \dot{W}\right) - \sum_n \varepsilon_{\dot{Z}_n} \cdot \dot{Z}_n - \dot{g} - \dot{\eta}
\end{aligned} \qquad [16]$$

The expression above shows that growth rate in TFP has been decomposed into six terms. The first is the **scale economy effect**. Economies of scale are realized if, when all other variables are held constant, changes in output quantities lead to reductions in the unit cost of production. This will be the case if the sum of the cost elasticities with respect to the output variables is less than one.

The second term is the **nonmarginal cost pricing effect**. This is equal to the difference between the growth rates of two output quantity indexes. One is the index used to compute TFP growth. The other output quantity index, denoted by $\dot{Y}^{\varepsilon}$, is constructed using cost elasticity weights. The Tornqvist index that we use to measure TFP should theoretically be constructed by weighting outputs by their shares of revenues. It can be shown that using cost elasticities to weight outputs is appropriate if the firm's output prices are proportional to its marginal costs, but revenue-based weights will differ from cost elasticity shares if prices are not proportional to marginal costs. Accordingly, this term is interpreted as the effect on TFP growth resulting from departures from marginal cost pricing.[48]

The third term is the **cost share effect**. This measures the impact on TFP growth of differences in the growth of input price indexes based on optimal and actual cost shares. This term will have a non-zero value if the firm utilizes inputs in non-optimal proportions.

The fourth term is the **Z variable effect.** It reflects the impact on TFP growth of changes in the values of the Z variables that are beyond management control.

The fifth term is **technological change**. It measures the effect on productivity growth of a proportional shift in the cost function. A downward shift in the cost function due to technological change will increase TFP growth.

The sixth term is the **inefficiency effect**. This measures the effect on productivity growth of a change in the firm's inefficiency factor. A decrease in a firm's inefficiency will reduce cost and accelerate TFP growth. Firms decrease their inefficiency as they approach the cost frontier, which represents the lowest cost attainable for given values of output quantities, input prices, and other business conditions.

[48] See Denny, Fuss and Waverman *op cit*, p. 197.

APPENDIX FOUR: ASSUMPTIONS UNDERLYING ECONOMIC INSIGHTS' MATHEMATICAL ANALYSIS

(*Note: the following discussion originally appeared in Kaufmann, L., **Reset of Default Price Path for Electricity Distribution Businesses: Submission to New Zealand Commerce Commission**, October 2009, pp. 35-40)*

4.2.1.2 Assumptions Underlying the Analysis

It should also be recognized that EI's recommended X factor formula is based on complex analyses developed in EI's Theoretical Report. The Theoretical Report is difficult to read carefully, since it is filled with dense (and perhaps intimidating) mathematical jargon and analysis. However, a careful reading of this document is instructive, for it reveals that EI's recommended formula rests on a number of assumptions which are unlikely to be satisfied in the present context.

For example, consider formula (194) in the Theoretical Report, which is replicated below.

(194) $(y^t, z^t, k) \in s^t$; $\quad t = 1,2$

EI emphasizes the importance of this equation to their analysis and the results that follow:

> What is fundamentally different about the new intertemporal utility maximisation problem as opposed to the one period utility maximisation problem considered in section 5.1 above is the treatment of capital in the constraints (194); ie note that *the capital variable k is constrained to be the same over the two periods* (italics in original; the reason this is true is that there is no time superscript on the variable k). It is this fixity that captures the nature of the sunk cost problem in the regulation of utilities. When a utility makes an infrastructure investment, it typically has to plan ahead over a long horizon because once the infrastructure has been built, it lasts for a long time and its maximum carrying capacity cannot readily be varied. Thus, at the beginning of period 1, we are assuming that the regulated firm must make a capital investment which will determine the capacity of the network not only for period 1, but also for subsequent periods. Of course, we have simplified the problem by assuming a horizon of only two periods but this limitation of our model can readily be generalised. However, the case of two

periods will suffice to illustrate the complexities of the regulator's optimal regulation problem.[49]

It can be seen that EI assumes that capital is fixed in all periods in this model. This is an extremely restrictive assumption which does not reflect the reality of the electricity distribution business. While it is true that EDBs make some investments that "determine the capacity of the network not only for period 1, but also for subsequent periods," they make many other investments on a more or less continual basis in response to ongoing changes in the demand for their services. Electricity distributors are not like natural gas pipelines, which typically transport energy along a fixed route from one defined point to another.[50] [51] Distributors deliver energy directly to end-user premises in a defined territory, and for most EDBs their customer mix is continually in flux, with new customers being added and others moving to new locations in the territory. These changes in customer mix and location lead to ongoing investments which are needed to connect and provide service to customers. These investments are an indispensable part of what EDBs do, and the EI Theoretical Report essentially assumes them away. Moreover, this assumption has concrete implications for EI's recommendations. As we have seen, EI's recommended X factor formula draws a sharp distinction between opex inputs and fixed, sunk capital costs, but makes no explicit provision for input price changes on new capital expenditures. This recommendation flows directly from EI's assumption (reflected in formula (194)) that all capital is essentially fixed or sunk.

The EI Theoretical Report uses many other assumptions to derive results that ultimately serve as recommendations. For example, equation (275) appears after differentiating a standard profit equation with respect to time and making some substitutions from other equations in the Report:

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[49] Economic Insights (2009a), pp. 48-49.

[50] And even if a gas pipeline continues to operate along a single fixed route, it can change the capacity of its infrastructure investment over its planned life *e.g.* by adding compression.

[51] It can also be argued that the Commission's view that transformer capacity be added to the system capacity output is not consistent with this assumption. This view implies that the capacity of distribution networks may not be fixed for all times based on a single investment; to at least some extent, it can be expanded incrementally, and flexibly, via transformer investments which are integrated with the more fixed and "sunk" system line investments.

$$(275)\quad \Pi'(t) = p'(t)\cdot y(t) - w'(t)\cdot z(t) - P_k'(t)\cdot k(t) + \tau(t)C_z(t)$$

$$+ [p(t)-\mu(t)]\cdot y'(t) + [P_k(t)-\pi(t)]\cdot k'(t).$$

This equation is the basis on which EI derives some of the key results, and ultimate recommendations, in the Theoretical Paper. It will be instructive to replicate in full the EI interpretation, and subsequent manipulation, of this expression that appears in the Technical Report, since it leads directly to a variant of the price cap formula that they propose for the DPP. This extended passage is replicated below:

> The first three terms on the right hand side of (275) can be converted into Divisia like indexes of output price change, $p'(t)\cdot y(t)$, minus a Divisia like index of opex input price change, $w'(t)\cdot z(t)$, minus a Divisia like index of amortisation price change, $P_k'(t)\cdot k(t)$. The last three terms are difficult to measure terms: the rate of opex technical change, $\tau(t)C_z(t)$, plus a weighted sum of output quantity changes, $y'(t)$, where the weights are the difference between the market prices for regulated outputs, $p(t)$, less the (unobserved) marginal cost weights, $\mu(t)$, plus a weighted sum of sunk cost capital quantity changes, $k'(t)$, where the weights are the difference between the allowed amortisation charges, $P_k(t)$, less the (unobserved) marginal benefit charges, $\pi(t)$, defined by (265). However, note that if $p(t)$ equals $\mu(t)$ and $P_k(t)$ equals $\pi(t)$ (which is an implication of first best optimal regulation), then the last two terms on the right hand side of (275) vanish and it also becomes straightforward to measure $\tau(t)$ (at least on an ex post basis) using equation (275).
>
> We will now assume that the regulator will force some proportional price change in the prices of regulated outputs at time t; ie we assume that the regulator changes all regulated prices according to the following formula:
>
> $$(276)\ p'(t) = \alpha'(t)p(t)$$
>
> where $\alpha(t)$ is set equal to 1. We also assume that the regulator has a target for the rate of change in profits for the regulated firm at time t equal to the rate $\beta R(t)$ say, where $R(t)$ is time t revenue. Thus, the regulator would like to determine a rate of change in regulated prices such that
>
> $$(277)\ \Pi'(t) = \beta R(t).$$
>
> Substituting (275) and (276) into (277) gives us the following solution for the allowable rate of increase in regulated prices $\alpha'(t)$:
>
> $$(278)\ \alpha'(t) = \beta + \{w'(t)\cdot z(t) + P_k'(t)\cdot k(t) - \tau(t)C_z(t) - [p(t)-\mu(t)]\cdot y'(t)$$

$$- [P_k(t)-\pi(t)]\cdot k'(t)\}/R(t).$$

Equation (278) is our desired approximate price cap formula. Suppose that the last two terms on the right hand side of (278) could be neglected. Further suppose that the profits of the regulated firm at time t are close to 0 and the regulator wants to keep profits close to 0 in the future. Under these conditions, the regulator would set β equal to 0 and (278) would simplify to:

$$(279)\ \alpha'(t) = \{w'(t)\cdot z(t) + P_k'(t)\cdot k(t) - \tau(t)C_z(t)\}/R(t).$$

We can further simplify (279) if we define the *Divisia input price indexes* for variable inputs and for sunk cost capital inputs as follows:
Define the *Divisia index of opex input price growth* at time t, $w_D'(t)$, and the *Divisia index of amortisation prices for sunk capital stocks* at time t, $P_{kD}'(t)$, as follows:

$$(280)\ w_D'(t) \equiv \Sigma_{k=1}^{K} [w_k(t)z_k(t)/w(t)^T z(t)][w_k'(t)/w_k(t)]\ ;$$

$$(281)\ P_{kD}'(t) \equiv \Sigma_{m=1}^{M} [P_{km}(t)k_n(t)/P_k(t)^T k(t)][P_{km}'(t)/P_{km}(t)]\ .$$

Substituting (280) and (281) into (279) gives us the following formula for the rate of increase in regulated prices (the X factor in price cap regulation):

$$(282)\ \alpha'(t) = [C_z(t)/R(t)]w_D'(t) + [C_k(t)/R(t)]P_{kD}'(t) - [C_z(t)/R(t)]\tau(t).$$

Thus, if we can neglect the last two terms in (278), (282) tells us that the allowable rate of price increase for all regulated products, $\alpha'(t)$, should be set equal to the ratio of opex costs to revenues, C(t)/R(t), times the Divisia rate of increase in opex prices, $w_D'(t)$, plus the ratio of time t allowable amortisation charges to revenues, $C_k(t)/R(t)$, times the Divisia rate of increase in these amortisation prices, $P_{kD}'(t)$, less the ratio of opex costs to revenues, C(t)/R(t), times the opex logarithmic rate of technical progress, $\tau(t)$. Formula (282) for the price cap is simple enough to be implementable provided that the regulator can make forecasts for the overall rate of increase in variable input prices, $w_D'(t)$, and for the anticipated rate of technical progress, $\tau(t)$.[52]

Equation (282) is essentially the X factor formula proposed by EI, although it is later updated to include economy-wide TFP growth and inflation. It can be seen that equation (282) was derived from a mathematical analysis that began with equation (275).

[52] Economic Insights (2009a), pp. 63-64.

The process was as follows. First, two assumptions were made – in equations (276) and (277) – which were substituted into (275); simplifying this expression led to equation (278). The authors then assumed "that the last two terms on the right hand side of (278) could be neglected," and eliminating these terms led to equation (279). Growth rates in two input price indices were then defined in equations (280) and (281), which were then substituted into (279). Simplifying this expression leads to equation (282), which is "the formula for the rate of increase in regulated prices (the X factor in price cap regulation)."

However, most of these assumptions and simplifications are problematic or unrealistic. For example, equation (276) is a mathematical representation of the assumption that "the regulator will force some proportional price change in the prices of regulated outputs at time t; i.e. we assume that the regulator changes all regulated prices according to the formula" which leads to price changes that are proportional to existing prices at all time periods t. This assumption is not valid in New Zealand; the Commerce Commission can only set a rate of change formula that depends on an X factor and inflation factor. The price changes that result from this price formula are not knowable *ex ante*, because CPI inflation is not known in advance. Therefore the regulator cannot "force" any specific price change at all (except perhaps irregularly when initial prices are reset at price reviews – but this is not the assumption that EI makes), let alone a price change that is necessarily proportional to existing prices.

Equation (277) is similarly problematic. It "assume(s) that the regulator has a target for the rate of change in profits for that regulated firm" that is proportional to that firm's change in revenues. This does not represent the way in which most regulators "target" profits, or change in profits. In nearly all practical cases, regulators link their profit targets to some target return on equity or rate base. Any revenue adjustments then depend on the relationship between current and target returns. Equation (277) inverts this relationship; in that equation, regulators link their profit targets to revenues, not earnings.

Equation (279) results when the last two terms of (278) are neglected. Footnote 67 explains why EI believes this assumption is reasonable:

> With increasing returns to scale in the regulated sector, we would expect the components of $p(t)-\mu(t)$ to be predominantly positive and with growth in the economy, we would also expect the components of $y'(t)$ to be positive and thus the term $-[p(t)-\mu(t)]\cdot y'(t)$ is likely to be negative. The last term is likely to be

small since the vector of fixed capital stock components k(t) is likely to remain roughly constant and hence k′(t) is likely to be small.[53]

It can be seen from this footnote that EI believes the first of the two neglected terms "is likely to be negative." It is unclear why a negative value makes this term unworthy of further consideration; certainly a non-zero value implies that, if this term is eliminated, the equation in (278) will no longer be true, which would vitiate the remainder of the analysis. EI also argues that the second term "is likely to be small since the vector of fixed capital stock components k(t) is likely to remain roughly constant and hence k′(t) is likely to be small." PEG does not agree with this assumption, since it is plainly inconsistent with the EDBs' recent investment experience. Table Two in our X Factor Recommendations Report shows that EDBs' capital stock is not "roughly constant" but in fact increasing in every year of the 1999-2008 sample period. Moreover, this rate of growth is increasing over time. It is very difficult to square the EDBs' observed history with the assumptions embedded in the EI theoretical analysis.

Since all of the assumptions necessary to move from equation (275) to equation (279) are problematic, it follows that equation (282) does not hold.[54] EI says that equation (282) represents the X factor in price cap regulation. Since a careful review of EI's analysis shows that this X factor derivation rests on problematic or unrealistic assumptions, it must be concluded that the analytical structure for EI's specific X factor formula is not sound.[55]

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[53] Economic Insights (2009a), p. 64

[54] Equations (280) and (281) are simply definitions and not problematic, but clearly if (279) is not true then any further mathematical manipulation past this point is superfluous.

[55] It may be argued that the specific equation used for the X factor formula in the Discussion Paper is (304) and not (282), so the points raised above are not valid. However, equation (304) simply embeds the basic formula reflected in (282) into a setting where economy-wide inflation measures are used to set the inflation factor in the CPI-X plan. Moreover, the sunk cost amortization schedule contained in equation (304) is ultimately derived from equation (285), where it is simply assumed (presumably on the basis of the analysis leading to equation (282)) that the price weights applied to changes in capital are observable amortization charges, not capital service prices. Equation (285) is therefore also an assumption, not a derivation from more fundamental economic analysis, and this assumption leads directly the input price differential recommended in the Discussions Paper. Thus it remains true that the EI recommendations rest entirely on assumptions, and these assumptions are not realistic.

On a different topic, we note that the weights in equation (283) that apply to the output changes are revenue share weights. The revenue share weights assumed in this equation apply for the remainder of EI's analysis in this chapter and hence are reflected in equation (304). PEG does not dispute this particular part of EI's analysis, but note that it implies revenue shares should be used in the calculation of the output quantity index, which differs from their statements in the Recommendations Report that cost elasticity shares be used.