Electricity Distribution Industry Productivity Analysis: 1996–2014

Report prepared for
Commerce Commission

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CONTENTS

EXECUTIVE SUMMARY

The Commerce Commission has engaged Economic Insights to provide information to inform the Commission's decisions regarding the 2014 default price–quality path reset for the 17 non–exempt electricity distribution businesses (EDBs). The reset will involve either resetting EDB starting prices taking account of current and future profitability or, alternatively, rolling over the prices applying in the last year of the preceding regulatory period. If prices are reset, this will be done by the application of the building blocks methodology. The information contained in this report relevant to the application of building blocks is:

- the long–run productivity growth rate for the electricity distribution industry, and
- opex and capital partial productivity growth rates for the electricity distribution industry.

If prices are instead rolled over from the last year of the preceding regulatory period, the Commission has indicated that the rate of change of prices will be determined using information on productivity and input price differentials between the distribution industry and the economy. This is the approach generally used in productivity–based regulation.

This report updates Economic Insights (2014a) to include data for 2013–14 and contains some changes in response to submissions received on our draft report. A separate report (Economic Insights 2014b) responds to submissions received by the Commerce Commission on productivity measurement issues.

In this report we calculate productivity growth rates for New Zealand EDBs using three different output specifications for the period 1996 to 2014. Growth rates are reported for total factor productivity (TFP) and opex and capital partial productivity for the industry as a whole and for the 17 non–exempt EDBs as a whole. The data used in the study are derived from the Information Disclosure Data. EDB TFP and partial productivity trend annual growth rates are presented in table A.

Building blocks X factor

In building blocks the starting prices and the rate of change (or X factor) are set to equate the net present values of forecast revenue and forecast costs (or the 'revenue requirement'). Changes in the X factor would be offset by changes in starting prices to maintain this equality. While there is an infinite number of starting price and X factor combinations that will achieve this equality, the Commerce Act states that the X factor should be based on the long run productivity improvement achieved by EDBs in New Zealand and/or comparable countries.

EDB productivity growth rates in New Zealand are found to have been broadly similar to those found in comparable countries such as Canada, those likely to be found in Australia and those reported in larger countries such as the US and the UK.

We have observations for New Zealand spanning the past 19 years. Normally one would seek as long a time period as possible to form an estimate of a long run growth rate. This implicitly assumes that growth occurs in a linear fashion and that there are no fundamental underlying changes occurring. There is some evidence from a range of comparable countries that a significant change in market conditions facing the energy supply industry has occurred recently due to more energy efficient appliances, more energy efficient buildings and the increasing penetration of rooftop solar PV panels. In this report we use results for the last decade in forming our recommendations.

A point consistently raised in submissions on productivity measurement aspects of the Commission's draft report was that Economic Insights (2014a) did not include the two–output specification used by the Commission in other parts of its rate of change modelling of EDB opex requirements under the building blocks approach. In this report we have reported productivity results using the two–output specification (covering customer numbers and circuit length) used by the Commission, the three–output specification we have used in previous reports for the Commission (covering energy, system capacity and customer numbers), and the four–output used by PEG (2013) in benchmarking work for the Ontario regulator (covering energy, ratcheted maximum demand, customer numbers and circuit length).

Table A: **Distribution industry productivity growth rates, 1996–2014, per cent pa**[a]

	1996–2014	1996–2004	2004–2014
TFP			
2 outputs	–0.18%	2.38%	–1.08%
3 outputs	0.81%	3.00%	–0.13%
4 outputs	0.08%	2.63%	–0.88%
Opex Partial Productivity			
2 outputs	0.45%	6.16%	–1.40%
3 outputs	1.44%	6.77%	–0.45%
4 outputs	0.70%	6.41%	–1.20%
Capital Partial Productivity			
2 outputs	–0.63%	–0.17%	–0.88%
3 outputs	0.36%	0.45%	0.08%
4 outputs	–0.38%	0.08%	–0.68%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates

For the building blocks X factor we recommend the two–output TFP trend growth rate for the period 2004–2014 of –1 per cent (rounded down for simplicity). In building blocks there is no need to include the differentials that are used in pure productivity–based regulation and hence it is appropriate to simply use the trend estimate of TFP growth itself.

Building blocks opex partial productivity growth

The other important productivity component in the building blocks approach is the rate of opex productivity growth to include in rolling forward the opex component of the revenue requirement. The Commission (2014a) has indicated it intends to roll opex forward by the sum of the forecast growth rate in opex prices plus the forecast growth rate in output (or scale effects) minus the forecast growth rate in opex partial productivity.

From table A we see that a similar situation exists with electricity industry opex partial productivity as with TFP. There was very strong trend annual growth in opex partial productivity of over 6 per cent from 1996 to 2004, mainly due to a reduction in the quantity of opex inputs of over 30 per cent in total. In the past decade, however, opex partial productivity trend annual growth has been –1.4 per cent as opex quantities have grown strongly.

Including a negative opex PFP growth rate in the opex rate of change formula also has potentially bad incentive properties. We have concerns with the incentive effects of including negative opex partial productivity growth rates in the rate of change formula – to some extent this would be akin to rewarding the EDBs for having previously overestimated future output growth and now entrenching productivity decline as the new norm. Such a situation is also arguably at odds with the workably competitive market assumptions in the Commerce Act. One would not expect to see ongoing productivity decline in a workably competitive market.

All else equal, failure to allow for the effect of past reset opex step changes in subsequent resets will lead to EDBs being over–remunerated as the measured opex productivity growth rate will underestimate the actual opex productivity growth rate. The opex partial productivity growth rate used in the rate of change formula needs to reflect productivity growth excluding step changes or else, if measured opex productivity is used, negative step changes may be required to equate the net present value of the actual opex requirements and the allowance resulting from application of the rate of change formula. To avoid negative step changes, this points to the use of a forecast productivity growth rate higher than measured from historic data spanning more than one regulatory period.

The recent opex PFP growth rate using the two–output specification is –1.4%. Mechanistic extrapolation of the recent rate would see a negative opex PFP growth rate being used in the opex rate of change used to forecast future opex requirements. However, this would have potentially adverse incentive effects and could lead to EDBs being over–remunerated due to progressive inclusion of step changes in base year opex. Our recommendation is for a zero opex PFP growth rate to be used in the rate of change formula.

Productivity–based regulation X factor

If the Commission opts to roll over EDB prices from the last year of the preceding regulatory period, it has indicated it will do so using a productivity–based regulation approach to setting the X factor. This involves taking the difference in TFP growth rates between the electricity distribution industry and the economy and subtracting from this the difference in input price growth rates between the electricity distribution industry and the economy.

The trend growth rate information required to calculate the productivity–based regulation X factor is presented in table B.

The first term involves the difference in TFP growth rates between the electricity distribution industry and the economy. Using the two–output TFP measure for EDBs and the SNZ MFP series (which only runs to 2013) for economy–wide productivity we obtain a productivity differential term of –1.2 per cent.

Turning to the input price growth difference between the electricity distribution industry and the economy, EDB input prices grew at a trend annual rate of 3.14 per cent over the last decade while economy–wide input prices grew by 2.87 per cent. This led to an input price differential of 0.27 per cent.

Table B: **Productivity–based regulation differentials, 1996–2014, per cent pa[a]**

	1996–2014	1996–2004	2004–2014
EDB Two–Output TFP Growth (a)	–0.18%	2.38%	–1.08%
Economy MFP Growth[b] (b)	0.61%	1.27%	0.14%
Productivity Differential (c) = (a) – (b)	–0.79%	1.12%	–1.22%
EDB Input Price Growth (d)	2.55%	1.63%	3.14%
Economy Input Price Growth[b] (e)	2.92%	2.94%	2.87%
Price Differential (f) = (d) – (e)	–0.38%	–1.31%	0.27%
X Factor (g) = (c) – (f)	–0.41%	2.43%	–1.49%

[a] EDB TFP uses the two–output specification: Customer nos (46%), Circuit length (54%), output cost shares in brackets.

[b] Trend calculated to 2013 as 2014 MFP data not yet released.

Source: Economic Insights estimates and Statistics New Zealand

Subtracting the input price differential from the productivity differential, we obtain a productivity–based regulation X factor –1.5 per cent.

1 INTRODUCTION

Seventeen New Zealand electricity distribution businesses (EDBs) are currently subject to a default price–quality path under Part 4 of the Commerce Act 1986 (the Act). Four months before the end of the regulatory period the Commerce Commission is required to reset the default price–quality paths applying to each EDB. Amongst other things, the Commission must reset starting prices, rates of change and quality standards. These paths will take effect from 1 April 2015.

Section 53P(3) of the Act states that the starting prices must either be:

- the prices that applied at the end of the preceding regulatory period; or
- prices, determined by the Commission, that are based on the current and projected profitability of each EDB.

The rate of change is the annual rate at which EDBs' maximum allowed prices can increase. This is expressed in the form 'CPI–X', meaning prices are restricted from increasing by more than the rate of inflation, less a certain number of percentage points, termed an 'X–factor'.

Sections 53P(6) and 53P(10) of the Act set out the constraints for the Commission's work, including:

- the rate of change must be based on the long–run average productivity improvement rate achieved by either or both of EDBs in New Zealand, and suppliers in other comparable countries, using appropriate productivity measures, and
- the Commission may not use comparative benchmarking on efficiency to set starting prices, rates of change, quality standards, or incentives to improve quality of supply.

The Commission has engaged Economic Insights to provide an estimate of the productivity improvement rate to inform the 2014 default price–quality path reset. Specifically, the Commission has asked Economic Insights to:

- provide an estimate of the long–run productivity improvement rate in the electricity distribution industry
- provide estimates of the operating expenditure and capital partial productivity improvement rates for the electricity distribution industry
- use publicly available information, adjusted as appropriate, and make available all datasets required for use by stakeholders, and
- advise on the robustness of using a productivity improvement rate based on data for all 29 EDBs or data for only those 17 EDBs that are subject to price–quality regulation.

Previously, productivity analysis has been used for determining the X–factor and allowances for operating expenditure where the building blocks approach is used to determine EDB starting prices based on the current and projected profitability of each EDB.

This report updates Economic Insights (2014a) to include data for 2013–14 and contains some changes in response to submissions received on our draft report. A separate report (Economic Insights 2014b) reviews submissions received by the Commerce Commission on productivity measurement issues.

2 THE USE OF PRODUCTIVITY ANALYSIS IN EDB REGULATION

This chapter provides a brief discussion of the role of productivity measurement in the economic regulation of natural monopolies such as EDBs.

2.1 What is total factor productivity?

Productivity is a measure of the physical output produced from the use of a given quantity of inputs. All enterprises use a range of inputs including labour, capital, land, fuel, materials and services. If the enterprise is not using its inputs as efficiently as possible then there is scope to lower costs through productivity improvements and, hence, lower the prices charged to consumers. This may come about through the use of better quality inputs including a better trained workforce, adoption of technological advances, removal of restrictive work practices and other forms of waste, and better management through a more efficient organisational and institutional structure. When there is scope to improve productivity, this implies there is technical inefficiency. This is not the only source of economic inefficiency. For example, when a different mix of inputs can produce the same output more cheaply, given the prevailing set of inputs prices, there is allocative inefficiency.

Productivity is measured by expressing output as a ratio of inputs used. There are two types of productivity measures: total factor productivity (TFP) and partial factor productivity (PFP). TFP measures total output relative to an index of all inputs used. Output can be increased by using more inputs, making better use of the current level of inputs and by exploiting economies of scale. The TFP index measures the impact of all the factors affecting growth in output other than changes in input levels. PFP measures one or more outputs relative to one particular input (eg labour productivity is the ratio of output quantity to labour input).

Forecast future productivity growth rates can play a key role in setting the annual revenue requirement used in building blocks regulation (as will be discussed in the following section). Productivity studies assist the regulator in determining likely future rates of productivity growth to build into annual revenue requirement forecasts. And, where the building blocks approach is not used (eg where starting prices are taken to be those applying at the end of the previous regulatory period), forecast TFP will have a more direct impact on the EDB's recoverable revenue (as will be discussed in section 2.3).

Productivity indexes are formed by aggregating output quantities into a measure of total output quantity and aggregating input quantities into a measure of total input quantity. The productivity index is then the ratio of the total output quantity to the total input quantity or, if forming a measure of productivity growth, the change in the ratio of total output quantity to total input quantity.

To form the total output and total input measures we need a price and quantity for each output and each input, respectively. The quantities enter the calculation directly as it is changes in output and input quantities that we are aggregating. The relevant output and input prices are used to weight together changes in output quantities and input quantities into measures of total output quantity and total input quantity using revenue and cost measures, respectively.

In forming the output measure for competitive industries, observed revenues shares are typically used to weight together the output quantities sold as price will approximate marginal cost in these industries. For natural monopoly infrastructure industries, however, prices charged will typically not equal marginal costs and pricing patterns may have evolved instead on the basis of convenience or attitudes to risk. Therefore, for industries such as electricity distribution, it is important to ensure that all dimensions of the output supplied are recognised and that prices reflecting marginal costs are used wherever possible to weight these output dimensions into a total output quantity measure. Using marginal cost weights is necessary to determine changes in costs that are due to changes in demands.

On the input side, the most difficult to measure component is the input of capital goods. Like other inputs and outputs, we need a quantity and cost for capital inputs. The appropriate measure to use for the capital input quantity in productivity analysis depends on the change in the physical service potential of the asset over time. For long–lived network assets such as poles, wires, transformers and pipelines, there is likely to be relatively little deterioration in physical service potential over the asset's life. In this case using a measure of physical asset quantity is likely to be a better proxy for capital input quantity than using the constant price depreciated asset value series as a proxy.

The traditional approach to measuring the annual user cost of capital in productivity studies uses the Jorgenson (1963) user cost method. This approach multiplies the value of the capital stock by the sum of the depreciation rate plus the opportunity cost rate minus the rate of capital gains (ie the annual change in the asset price index).

For traditional productivity studies with a limited history of investment data available, the asset value series is typically rolled forwards and backwards from a point estimate using investment and depreciation series. The point estimate would typically reflect the market value of assets at that point in time. It would be standard practice to take the earliest point estimate of the capital stock available, provided there was reasonable confidence in the quality of the valuation process. In the case of energy distribution, sunk assets and new investment have traditionally been treated symmetrically and the concept of financial capital maintenance (FCM) has been an important feature of building blocks regulation in particular. To ensure ex–ante FCM is satisfied, it is important to allocate an annual user cost (AUC) to capital inputs that is broadly analogous to the return of and return on capital components used in calculating the building blocks capital component.

2.2 Building blocks regulation

The Commission currently uses the building blocks approach when it resets EDB starting prices taking account of the current and projected profitability of each EDB. The building blocks approach to price regulation involves calculating an annual 'revenue requirement' for each EDB based on the costs it would incur if it was acting prudently. The costs are made up of opex, capital costs and a benchmark tax liability (which usually takes account of the differences between regulatory and taxation parameters and allowances). Capital costs are, in turn, made up of the return of capital and the return on capital. The return of capital is typically calculated as straight–line depreciation on the DB's opening regulated asset base (RAB) calculated over its estimated remaining life plus straight–line depreciation of assets added during the period calculated over their estimated total lives. The return on capital is the opening RAB multiplied by an opportunity cost rate. The opportunity cost rate is the weighted average cost of capital (WACC) which takes account of the different costs of the nominated debt and equity components of the RAB.

Financial capital maintenance (FCM) is a key principle in the building blocks approach. FCM means that a regulated business is compensated for prudent expenditure and prudent investments such that, on an ex–ante basis, its financial capital is at least maintained in present value terms.

Since the building blocks method involves setting the price cap for each DB at the start of the regulatory period, forecasts have to be made of the annual revenue requirement stream over the coming regulatory period and of the quantities of outputs that will be sold over that period. Since the opening RAB for the regulatory period will be (largely) known, the annual revenue requirements for the upcoming regulatory period can be forecast based on forecasts of opex and capex.

Once the forecasts of annual revenue requirements and output quantities have been made, the P_0 and X factors are set so that the net present value of the forecast operating revenue stream over the upcoming regulatory period is equated with the net present value of the forecast annual revenue requirement stream. There is an infinite number of starting price and X factor combinations which will satisfy this condition. However, in the case of New Zealand, the Act specifies that the X factor is to be set at an exogenous value based on the long–run average productivity improvement rate achieved by EDBs. This means the starting price is then set to equate the net present value streams.

If the starting prices are set based on the current and projected profitability of each supplier, then the rate of change will not affect the amount of revenue the individual EDB can expect to recover over the regulatory period. This is because starting prices for each regulated EDB would simply be adjusted to offset any alteration to the common rate of change to maintain the equality between the present value of expected revenues and the present value of expected costs for that EDB over the regulatory period. This means the regulatory outcome for each EDB is not affected by the measured long–run average productivity improvement rate used to set the rate of change of prices.

However, the forecast partial opex and capital productivities can impact the level of forecast costs and therefore the present value of allowable revenue over the regulatory period for each EDB. In the case of opex, the Commission (2014a) has indicated it expects forecast opex to be set using the following formula:

> operating expenditure$_t$ = operating expenditure$_{t-1}$ × (1 + Δ due to network scale effects – Δ operating expenditure partial productivity + Δ input prices).

This is the ‘rate of change’ formula commonly used in building blocks whereby the opex forecast is rolled forward by the sum of forecast input price growth plus forecast output growth minus the forecast rate of opex partial productivity growth. A higher forecast opex partial productivity growth rate will thus lead to a lower opex revenue requirement over the next regulatory period for EDBs.

Since productivity analysis provides information on the partial productivity of the overall capital stock, rather than of individual year's capex, it typically plays a limited role in forming annual capex requirements forecasts under the building blocks approach.

2.3 Productivity–based regulation

If the Commission decides to set starting prices to be the same as those applying at the end of the previous regulatory period then the X factor acquires considerably greater importance and will have a direct bearing on EDBs' profitability. In this case the situation would be more akin to traditional productivity–based regulation.

Because infrastructure industries such as the provision of energy distribution networks are often subject to decreasing costs in present value terms, competition is normally limited and incentives to minimise costs and provide the cheapest and best possible quality service to users are typically not strong. The use of CPI–X productivity–based regulation in such industries attempts to strengthen the incentive to operate efficiently by imposing pressures on the network operator similar to the process of competition. It does this by constraining the EDB's output price to track the level of estimated efficient unit costs for the industry. The change in output prices is 'capped' as follows:

(1) $$\Delta P = \Delta W - X \pm Z$$

where Δ represents the proportional change in a variable, P is the maximum allowed output price, W is a price index taken to approximate changes in the industry's input prices, X is the estimated TFP change for the industry and Z represents relevant changes in external circumstances beyond managers' control which the regulator may wish to allow for. Ideally the index W would be a specially constructed index which weights together the prices of inputs by their shares in industry costs. However, this price information is often not readily or objectively available. A commonly used alternative is to choose a generally available price index such as the consumer price index or GDP deflator.

Productivity–based regulation argues that in choosing a productivity growth rate to base X on, it is desirable that the productivity growth rate be external to the individual firm being regulated and instead reflect industry trends at a national or international level. This way the regulated firm is given an incentive to match (or better) this productivity growth rate while having minimal opportunity to 'game' the regulator by acting strategically.

As outlined in Lawrence (2003), traditional productivity–based regulation has typically been implemented using CPI–X price caps where, as the result of choosing the CPI to index costs, the formula for the X factor takes on the following 'differential of a differential' form:

(2) $$X \equiv [\Delta TFP - \Delta TFP_E] - [\Delta W - \Delta W_E] - \Delta M.$$

where the E subscript refers to corresponding variables for the economy as a whole and M refers to monopolistic mark–ups or excess profits. What this formula tells us is that the X factor can effectively be decomposed into three terms. The first differential term takes the difference between the industry's TFP growth and that for the economy as a whole while the second differential term takes the difference between the firm's input prices and those for the economy as whole. Thus, taking just the first two terms, if the regulated industry has the same

TFP growth as the economy as a whole and the same rate of input price increase as the economy as a whole then the X factor in this case is zero. If the regulated industry has a higher TFP growth than the economy then X is positive, all else equal, and the rate of allowed price increase for the industry will be less than the CPI. Conversely, if the regulated industry has a higher rate of input price increase than the economy as a whole then X will be negative, all else equal, and the rate of allowed price increase will be higher than the CPI.

The change in mark–up term in (2) would be set equal to zero under normal circumstances but if the target firm was making excessive returns, then this term could, in principle, be set negative (leading to a higher X factor).

2.4 Earlier New Zealand electricity distribution productivity studies

The former thresholds regime was based on quantitative work reported in Lawrence (2003). To capture the multiple dimensions of lines business output Lawrence (2003) measured distribution output using three outputs: throughput, system line capacity and connection numbers. Inputs were broken into four categories: operating expenses, overhead lines, underground cables, transformers and other capital.

Lawrence (2003) used the Fisher TFP index method to calculate the productivity performance of the electricity distribution industry as a whole. For the period 1996 to 2002 aggregate distribution TFP was found to have increased at a trend annual rate of 2.1 per cent, 1.0 per cent above that for the economy as a whole.

Lawrence (2003) found there are several conflicting pieces of information on the movement of lines business input prices relative to those for the economy as a whole. Wage rates in the electricity, gas and water sector had increased by less than those for all industries in the nine years to March 2003 although the gap had narrowed somewhat in the last two years and anecdotal evidence at the time pointed to a shortage of linesmen.

Capital price indexes gave conflicting information with one power line price index increasing faster than the capital price index for all sectors and the other major power line price index increasing less rapidly than the all sectors index. Producer price indexes, on the other hand, show that lines business input prices had increased less rapidly than input prices for all industries. The implicit total input price index derived from the Lawrence (2003) distribution database increased at the same trend rate as economy–wide capital prices but substantially less than economy–wide wage rate and producer input price indexes. In light of the conflicting information coming from the official statistics Lawrence (2003) recommended setting the input price growth differential to zero.

Combining the 1.0 per cent productivity growth differential and the zero per cent input price growth differential, Lawrence (2003) recommended an overall X factor of 1.0 per cent for the electricity distribution industry and this was adopted by Commerce Commission (2003).

Lawrence (2007) updated the EDB productivity analysis presented in Lawrence (2003) to cover the years 2004 to 2006. Lawrence (2007) made some minor revisions to the data used in the earlier study for the years 1996 to 2003 as errors contained in the official Disclosure Data had progressively been identified and corrected. To maintain maximum comparability with Lawrence (2003), Lawrence (2007) used an adjusted asset value series that excluded the

2004 optimised deprival value (ODV) asset revaluations.

Extending the period covered forward to 2006 led to the electricity distribution industry output trend growth rate increasing to 1.6 per cent per annum but inputs had also increased by a trend growth rate of 0.7 per cent, instead of decreasing as they had up to 2002. This led to the industry TFP annual trend growth rate for the 11 year period as a whole falling to 0.9 per cent. TFP fell by just under 2 per cent in each of the years 2004 and 2005 before increasing marginally in 2006.

The fall in electricity distribution industry TFP in 2004 and 2005 was found to be mainly in response to a sharp increase in opex and strong growth in the capital stock, particularly increases in underground cables and transformers. The quantity of opex was found to have increased by 14 per cent over this two year period, accounting for nearly 40 per cent of the increase in the total input quantity. Part of the reason for this increase was thought to be large increases in opex for the three businesses that took over the former UnitedNetworks. A series of unusual storms around this time may also have contributed to the observed opex increases.

In 2009 the Commission engaged Economic Insights to examine the electricity distribution industry's productivity performance and make recommendations regarding the X factor that should apply in the next regulatory period. Economic Insights (2009a) noted that the earlier output specification used in Lawrence (2003, 2007) made no allowance for the contribution of distribution transformer capacity to overall system capacity. Distribution transformer capacity had grown rapidly over the preceding several years and failure to recognise the important contribution of increased distribution transformer capacity was likely to have led to the system delivery capacity measure (which reflects the ability to meet capacity demands) being biased downwards.

Using the broader definition of system delivery capacity in the TFP analysis which recognised the contribution of transformer capacity as well as line capacity, led to industry TFP growing strongly to 2003 and then levelling off after that. Over the 13 year period from 1996 to 2008, industry TFP grew at a trend rate of around 1.1 per cent per annum leading to a very small productivity growth differential of effectively zero relative to the economy as a whole.

Economic Insights (2009a) found that the non–exempt part of the industry exhibited somewhat stronger TFP growth than the industry as a whole. TFP trend growth rates for this industry segment were around 1.5 per cent per annum. This segment accounted for 80 per cent of industry throughput and customer numbers. Calculating the productivity growth differential term on the basis of the 'non–exempt' portion of the industry would have led to a productivity growth differential of around 0.4 per cent but a conservative course of action of setting the productivity growth differential term in the X factor to zero based on the overall industry and market sector performance was recommended.

Economic Insights (2009a) also found that, using the rigorous amortisation charge approach to calculating annual capital user costs which takes account of ex ante FCM, the distribution industry as a whole had exhibited slightly slower input price growth than the economy as a whole over the preceding 13 years. This pointed to a small input price growth differential of in the order of –0.3 per cent per annum but a conservative course of action in favour of the EDBs of setting the input price growth differential term in the X factor to zero was recommended. Since the X factor is the difference between the productivity growth differential and the input price growth differential and each of these had been conservatively recommended to be set to zero, it followed that the X factor was also recommended to be zero.

Economic Insights (2009a) used a TFP specification with three outputs:

- throughput in GWh
- customer numbers
- system capacity based on the product of overall system mains length and the last step transformer capacity (kVA*kms)

and four inputs:

- opex
- overhead lines in MVA–kms (being the summation of system overhead mains lengths at various voltages multiplied by an MVA carrying capacity for each voltage level)
- underground lines in MVA–kms
- transformers in kVA and other capital

Output quantities were output cost share weighted and inputs weights were formed using an exogenous capital cost taking account of FCM.

In 2009 the Electricity Networks Association engaged Pacific Economics Group (PEG) to calculate electricity distribution TFP growth rates and these were also considered by the Commission. Despite using a different time period and specification, PEG (2009) found similar electricity distribution industry productivity results to Economic Insights (2009a). PEG found an annual TFP growth rate of 1.2 per cent for the 10 years to 2008 and recommended an X factor range of between 0.19 per cent and –0.63 per cent.

PEG (2009) used a TFP specification with three outputs:

- customer numbers
- throughput in GWh
- peak demand as measured by the non–coincident peak in GW

and two inputs:

- opex
- capital (measured by constant price depreciated asset value).

Outputs were revenue share weighted and inputs weights were formed using an endogenous capital cost (the difference between revenue and opex).

Based on the findings of Economic Insights (2009a) and PEG (2009), the Commission set an X factor of 0 per cent (leading to a rate of change of CPI–0 per cent) and also assumed an opex partial productivity growth 0 per cent in constructing its forecast of opex requirements.

3 DATA USED AND SPECIFICATIONS EXAMINED

3.1 Data sources and adjustments

The starting point for the database used in this study is the database used in Economic Insights (2009a). We extend this to the 19 data years 1996–2014 to calculate trend rates of aggregate industry and aggregate non–exempt EDB productivity growth. The 1995 data year was discarded due to the apparent teething problems with providing Information Disclosure Data (IDD) in the first year and the absence of ODV estimates. A number of assumptions outlined in Lawrence (2003) are also made in this study to address opex data discontinuities in the 1999 financial year and the effects of the extended Auckland CBD outage.

Data for each of the individual EDBs are aggregated up to industry level for each variable. These data were first required for the 1995 March year and included physical, service quality and financial information. Legal (as opposed to reporting) separation of distribution and retail activities occurred during the 1999 financial year[1], and the disclosure data requirements were revised at that time. Some corrections were made to the data in Lawrence (2003) to reflect the businesses' responses to the opportunity to comment on the data set and to ensure maximum consistency of the data through time. Further minor corrections were made in Lawrence (2007) and Economic Insights (2009a) as it became apparent that different EDBs had reported variables on different bases or changed their basis of reporting through time and further corrections have been made in the current study to maintain consistency between the earlier information disclosure formats and the revised format adopted for the 2008 reporting year and later years.

One example of a minor issue with the pre–2008 IDD is that with the release of more detailed data (for some areas) in the new IDD data from 2008 onwards, it has become apparent that EDBs had not reported distribution transformer capacity consistently before 2008. Some had included customer–owned transformers while some had only included transformers they owned themselves. Since it is no longer possible to readily recover consistent data for the earlier period and given that the focus of this study is on productivity growth and not productivity levels, we have continued the series for each EDB on the same basis as it was reported in the pre–2008 IDD.

In a few cases key series contained in the pre–2008 IDD used in the productivity analysis have not been continued in the new IDD. The most important of these relate to opex where the direct cost per line kilometre and indirect cost per customer series were discontinued in the new IDD. Our previous productivity analysis used these ratios scaled up by line length and customer numbers, respectively, as the best source of opex data for productivity analysis purposes. For productivity analysis we require the opex series to reflect the use of physical, non–durable inputs (ie labour, materials and services) each year and to exclude other items which might be included for accounting purposes. For example, a number of EDBs included items such as line charge rebates in the opex series reported in the pre–2008 IDD but these were excluded from the direct cost and indirect cost ratios.

[1] We adopt the convention that financial years are referred to by the year in which they end.

We have compared our 2008 scaled up opex with the 2008 opex reported in the new IDD[2]. For around a third of the EDBs the new 2008 opex value is within 1 per cent of our scaled up 2008 opex value based on the direct and indirect ratios. For another third of the EDBs the new value is within between 1 and 5 per cent of our scaled up 2008 opex value. But there are several EDBs where the difference is more than 5 per cent with some being higher and some being lower than the corresponding scaled up value. Fully resolving the reasons for these variations is beyond the scope of the current project. Since we are confident that the former direct and indirect cost ratios captured the actual physical input use required for productivity analysis, we have opted to roll our former series for each EDB forward beyond 2008 by the change in the overall opex reported in the new IDD for that EDB. Given the spread of the variations in the two series in 2008, the aggregate industry opex series is relatively insensitive to whether no adjustment is made for the 2008 reporting change, whether the post–2008 series is spliced onto the series we have used previously (the approach adopted here) or whether the reverse splicing is done.

Another problematic area is capital data. Optimised deprival valuations (ODV) were only first done on a consistent basis across EDBs in 2004 and consistent roll forward data is only available in the IDD itself from 2008 onwards (although these data were subsequently collected by the Commission for the years 2005–2008 and these were used in Economic Insights (2009a)). Furthermore, the capex data reported in the pre–2008 IDD do not reflect actual expenditure by the EDB but rather valuations based on physical work done and using the specified ODV unit rates. In Economic Insights (2009a) we formed an estimate of a consistent capex series for the years before 2004 using changes in reported asset values and related data. This series was used in constructing the annual user cost of capital amortisation value. It is used for that purpose in this report and also to form a constant price depreciated asset value series (as will be outlined in section 3.4).

A maximum demand variable is used in the current study for the first time. The EDB coincident maximum demand series contains a number of anomalies for the years up to and including 2003. The most notable of these is a step change in the United Networks Ltd (UNL) series in 1999 which leads to a doubling of its reported maximum demand in that and subsequent years despite no unusual change occurring in other output variables such as energy throughput or customer numbers. We adjust for this anomaly by assuming UNL's 1998 maximum demand was the same as that reported for 1999 and splicing the series for the earlier years onto this. Other apparent maximum demand anomalies were observed for Centralines in 2002 and Marlborough Lines in 2003 when the reported values approximately doubled for those years only in both cases. We have assumed the correct value in both cases was equal to the previous year's value for each EDB.

For some variables the data files supplied by the Commission contain minor revisions to values back to around 2005 and these are included in the updated database.

Orion is excluded from the database and the analysis given its special circumstances and the difficulty of objectively adjusting its data to exclude the effects of the February 2011 Christchurch earthquake.

[2] Data for 2008 were available on both bases.

The key variables for the 19 year aggregate industry database and the non–exempt EDB database are listed in appendix A.

3.2 Output and input specifications examined

Economic Insights (2009a) used a TFP specification which included three outputs (throughput, overall system capacity and connections) and four inputs (opex, overhead lines, underground cables, and transformers and other assets). Output weights were allocated based on econometrically estimated output cost shares (ie the contribution of each of the three outputs to total costs). Capital input quantities were proxied by physical asset measures while capital input costs were proxied by an amortisation charge.

There has been much debate about whether outputs should be measured on an 'as billed' basis or on a broader 'functional' basis. This distinction arises because EDB charging practices have typically evolved on an ease of implementation basis rather than on a cost reflective basis. Hence, many EDBs levy a high proportion of charges on energy throughput even though changes in throughput usually have little real impact on the costs they face and dimensions that customers may value highly such as reliability, continuity or speedy restoration after any interruption are not explicitly charged for at all. Under productivity–based regulation a case can be made that the 'billed' output specification should be used as output (and, hence, productivity) needs to be measured in the same way that charges are levied to allow the EDB to recover its costs over time. Economic Insights (2009b) showed that this can also be achieved under a functional output specification provided billed outputs are included as a subset of functional outputs and appropriate weights are used. However, under building blocks regulation there is typically not a direct link between the revenue requirement the EDB is allowed and how it structures its prices. Rather, the regulator typically sets the revenue requirement based on the EDB being expected to meet a range of performance standards (including supply availability and reliability performance). In the building blocks context it will be important to measure output in a way that is broadly consistent with the output dimensions implicit in the setting of EDB revenue requirements.

Economic Insights (2009) used a functional outputs specification concentrating on the supply side, ie giving EDBs credit for the network capacity they have provided. In consultation undertaken by the Australian Energy Regulator (AER) in 2013, many user groups – and also some Australian EDBs – argued for the inclusion of demand side functional outputs so that the EDB is only given credit for network capacity actually used and not for capacity that may be installed but excess to users' current or reducing requirements. Including observed maximum demand instead of network capacity was argued to be a way of achieving this. However, this measure would fail to give the EDB credit for capacity it had been required to provide to meet previous maximum demands which may have been higher than those currently observed. Economic Insights (2013a) suggested that inclusion of a 'ratcheted peak demand' variable may be a way of overcoming this problem and Pacific Economics Group Research (PEGR 2013a,b) also used a similar variable in work on Ontario electricity distribution. This variable is simply the highest value of peak demand observed in the time period up to the year in question for each EDB.

PEGR (2013a) included a total of four functional outputs (energy delivered, ratcheted maximum demand, customer numbers and circuit length). We believe this specification has a number of attractions – it captures the key elements of system capacity while also acknowledging a demand side component and overcoming some of the limitations of other functional output specifications. The earlier PEG (2009) New Zealand study used a billed outputs specification with high level proxies for the quantities actually charged for[3].

A point consistently raised in submissions on productivity measurement aspects of the Commission's draft report was that Economic Insights (2014a) did not include the two–output specification used by the Commission in other parts of its rate of change modelling of EDB opex requirements. The two–output specification used by the Commission included customer numbers and line length as the only outputs. In this report we include three output specifications as outlined in table 1.

Table 1: **EDB output specifications examined**

Description	*Components included and weight applied*	*Weighting basis*
2–outputs	Customer nos (46%), Circuit length (54%)	Output cost share
3–outputs	Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)	Output cost share
4–outputs	Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)	Output cost share

Output cost shares are derived by estimating Leontief cost functions for each of 24 EDBs and taking a weighted average of estimated output cost shares across the sample of 456 observations (24 EDBs across 19 years each). The weights for each observation are based on its share in the total estimated cost across the entire sample. Given the difficulty of obtaining consistent series for the EDBs involved in the split up of UNL in 2003, we exclude Powerco, Unison, UNL, Vector and Wellington from the sample for econometric analysis. PEGR (2013a) also excluded the largest Ontario EDBs from its econometric estimation of output cost shares given a similar disparity in EDB sizes. Orion is also excluded from the econometric analysis as it is from the sample for all the reported analysis. The resulting output cost share estimates for the four functional output specifications are reported in table 1. The cost function estimation and cost share calculation process used is described in appendix B.

Turning to the specification of inputs, there has also been considerable debate around the best way to proxy the quantity of the annual input of capital in economic benchmarking studies. Some studies have used physical quantity based measures (eg MVA–kms of lines and MVA of transformer capacity) which assume 'one hoss shay' depreciation (of physical capacity) while others have used a deflated depreciated asset value series to proxy annual capital input quantity. The latter approach typically involves a straight–line depreciation assumption.

There have also been different approaches adopted to measuring the annual user cost of capital. Economic Insights (2009a) adopted an exogenous amortisation approach which recognised the principle of FCM which is central to building blocks regulation. PEG (2009) adopted a simpler endogenous method whereby the difference between revenue and opex is allocated as the annual user cost of capital.

In this study we use physical quantities to proxy annual capital input quantity and we use the exogenous amortisation–based annual user cost of capital as this is the best approach to use in

[3] In a study for the Victorian gas distribution businesses Economic Insights (2012) undertook a detailed comparison of using a billed outputs specification using quantities actually charged for versus a functional outputs specification.

building blocks productivity applications (since the annual user cost is calculated in an analogous way to the return of and return on capital and tax components in building blocks). A pre–tax real weighted average cost of capital (WACC) of 5.1 per cent is used in the amortisation calculation. A pre–tax real WACC is used as the tax component is not normally separately included in productivity studies in the same way it is in building blocks calculations.

A detailed discussion of a wider range of output and input specification issues in EDB productivity measurement can be found in the recent Economic Insights (2013b) report for the AER.

3.3 Output and input definitions

Output quantities

Throughput: The quantity of electricity distribution throughput is measured by the number of kilowatt hours of electricity supplied.

Overall system capacity: Overall system capacity is measured by the product of the electricity distribution industry's installed distribution transformer kVA capacity of the last level of transformation to the utilisation voltage and its totalled kilometres of mains length (inclusive of all voltages but excluding streetlighting and communications lengths).

Connections: Connection dependent and customer service activities are proxied by the EDB's number of connections.

Maximum demand: The sum of coincident maximum demands for each of the included EDBs. It is thus a non–coincident maximum demand measure for the electricity distribution industry as a whole and for the subset of non–exempt EDBs.

Ratcheted maximum demand: The sum of ratcheted coincident maximum demands for each of the included EDBs where ratcheted maximum demand for a particular year is the highest maximum demand observed in the sample period up to that point. PEGR (2013a,b) refers to an analogous measure as 'system capacity peak demand'.

Circuit length: The sum of overhead and underground circuit kilometres.

Output weights

To aggregate a diverse range of outputs into an aggregate output index using indexing procedures, we have to allocate a weight to each output. For a functional output specification the weights should reflect the relative costs of producing each output. We use the output cost shares derived from the econometric estimation of Leontief cost functions as output weights for the functional output specifications in table 1 above. Table 1 also presents the values of these estimated output shares and the Leontief methodology is presented in appendix B.

Total electricity distribution industry revenue is taken to be 'deemed' revenue comprising line charges plus revenue from 'other' business plus AC loss rental rebates less payment for transmission charges less avoided transmission charges less AC loss rental expense paid to customers. Line charge revenue is taken to be net of discounts to customers.

Input quantities

Operating expenditure: The quantity of electricity distribution operating and maintenance expenses is derived by deflating the sum of the grossed up values of direct costs per kilometre and indirect costs per customer by a composite index of labour costs and the all industries producer price index for inputs. The grossed up values of direct costs per kilometre and indirect costs per customer are used as the value of operating costs because these measures best reflect the purchases of actual labour, materials and services used in operating the electricity distribution system and exclude rebates. As discussed in section 3.1, the 2008 grossed up opex values for each EDB are rolled forward using the change in total reported opex in the IDD for years after 2008 as the requisite ratio data were not included in the latest version of the IDD. The all industries producer price index for inputs is used in forming the opex price index in preference to the corresponding Electricity, gas, water and waste (EGWW) sector index as the latter is relatively volatile, likely reflecting the influence of parts for the sector outside the electricity distribution industry. To be consistent with the approach adopted by the Commission in other parts of its rate of change method of rolling forward opex input requirements, the all industries labour cost index is used to measure the price of labour inputs. In our earlier productivity studies for the Commission we have used the sector–specific labour cost index as the sole measure of EDB opex prices.

Overhead network: The quantity of poles and wires input in the overhead network is proxied by the electricity distribution industry's overhead MVA kilometres. The MVA kilometres measure provides a means of adding up the capacity of lines of differing voltages and capacities in an objective and consistent manner. Low voltage distribution lines were converted to system capacity in MVA kilometres using a factor of 0.4, 6.6kV high voltage distribution lines using a factor of 2.4, 11kV high voltage distribution lines using a factor of 4, 22kV high voltage distribution lines using a factor of 8, 33kV high voltage distribution lines using a factor of 15, 66 kV lines using a factor of 35, and 110 kV lines using a factor of 80. These factors are based on Parsons Brinckerhoff Associates (2003).

Underground network: The quantity of underground cables input is proxied by the electricity distribution industry's underground MVA kilometres calculated using the same factors as listed above.

Transformers and other assets: The quantity of transformer and other asset inputs is proxied by the kVA of the electricity distribution industry's installed distribution transformers.

Input weights

For the productivity analysis we take total costs to be the sum of operating expenditure and capital amortisation charges. The method used to calculate amortisation charges is described in section 3.3. The weight given to opex is its share in total cost. The weights given to the three capital input components are the shares of each component in the 2004 ODV multiplied by the overall capital share in total cost.

For the econometric estimation of cost functions at the EDB level, the value of total costs is formed by summing the estimated value of operating expenditure and 12.5 per cent of (estimated) indexed historic cost (IHC). The latter is based on the NZIER (2001) assumption of a common depreciation rate of 4.5 per cent and an opportunity cost rate of 8 per cent for capital assets. This was shown in Economic Insights (2009a) to be a close approximation to the pre–tax amortisation charge.

Non–exempt EDBs

The Commission has requested Economic Insights to prepare TFP estimates for the subset group of non–exempt EDBs as well as for the electricity distribution industry as a whole. The Act specifies that 'consumer–owned' EDBs are exempt from price–quality regulation. Twelve EDBs qualify for 'consumer–owned' status in that they:

- are 100 per cent consumer owned (trust owned) as required by criterion (a)
- have trust deeds meeting the election requirements stipulated by criterion (b)
- have at least 90 per cent of consumers benefiting from income distribution as required by criterion (c), and
- have less than 150,000 ICPs as required by criterion (d).

The 12 EDBs are:

- Buller Electricity
- Counties Power
- Electra
- MainPower New Zealand
- Marlborough Lines
- Network Waitaki
- Northpower
- Scanpower
- The Power Company
- Waipa Networks
- WEL Networks, and
- Westpower

Our non–exempt results thus exclude these 12 EDBs.

3.4 Amortisation charges and constant price asset values

FCM consistent amortisation charges

FCM–consistent amortisation charges can be calculated using a large number of different capital charge profiles. In this study, the profile assumes straight line depreciation of existing assets and capital expenditure based on respective asset lives and estimates the charges in nominal terms for each year using a building blocks approach. This entails adjusting the starting point asset value each year for inflation, the carry forward of depreciation charges adjusted for inflation and the use of a real pre–tax return each year. As a real pre–tax rate of return is used and assets are revalued to take account of inflation there is no need to make an additional adjustment to remove revaluation gains from the estimated nominal capital charges.

Consistent with the decision in Commerce Commission (2014c), amortisation charges are calculated using the 67th percentile pre–tax nominal discount rate of 7.2 per cent. The pre–tax real discount rate is derived by deflating by the geometric mean of the 5–year forecast CPI inflation rate deflated with a Fischer function.

Starting point asset values, new investment and asset lives

The amortisation charges for system fixed assets were calculated for the electricity distribution industry as a whole for the period 1996 to 2014. As in Lawrence (2003, 2007) non–system fixed assets are excluded due to their relatively small size. As noted in Economic Insights (2009a), an 'IHC' asset value series is available from 2004 to 2008 using the 2004 ODV revaluations as the starting point. The components required to roll back before 2004 on an IHC basis are not available and so the earlier ODV series from Lawrence (2003, 2007) was spliced onto the 2004 ODV to proxy the IHC series from 1996 to 2003.

The ODV for year ended 2004 was used as a base to determine the amortisation charge over the remaining life of the assets from 2005 onwards. A charge also had to be calculated for new investment from 2005 to 2014 to recover the cost of new investments over their assumed lives. Asset additions data from the IDD were used as estimates of new investment from 2005 to 2014.

To calculate charges from 1996 to 2004 a similar process was applied to the estimate of capital as at the end of 1995. Since no ODV value was reported in the 1995 IDD, it is estimated by applying the average annual growth rate of the ODV series from 1996 to 2003 to the 1996 reported ODV.

Estimated nominal asset additions for 1996 to 2003 were calculated by use of the perpetual inventory formula $I_t=K_t-(1-d)K_{t-1}(1+\rho)$, where the depreciation rate 'd' was assumed to be the same as the average of reported depreciation for the period 2005 to 2014 (3.79 per cent for the industry and 3.71 per cent for non–exempt EDBs) and the inflation rate 'ρ' was based on the all groups CPI from Statistics New Zealand.

In order to calculate the amortisation charges, asset lives for new investment and remaining asset lives for the asset value bases at the start of 1996 and start of 2005 had to be estimated. Estimates of total asset lives and remaining asset lives as of March 2007 were obtained from Farrier Swier Consulting (2007). Based on this report, the mean standard asset life for the total asset base was 52 years and the ratio of the average age of the network to mean standard lives was 0.49 as of March 2007. Based on these estimates, the remaining mean asset life of the existing asset based was assumed to be 26 years as of March 2007 (37 years in 1996) and the mean standard asset life of new investment was assumed to be 52 years.

The charges prior to 2005 were also adjusted to remove discontinuity in the two series (given that the data prior to 2004 provide only an approximation to relevant IHC series). This was done by obtaining estimates of amortisation charges for 2005 by both approaches and applying the ratio of the 2005 estimate based on the 2004 ODV asset value to the 2005 estimate based on the 1996 spliced ODV and IHC asset value, to the estimated charges based on the latter asset values.

Nominal amortisation charges based on a building blocks approach

The amortisation charges comprise a return on capital and a return of capital in nominal terms for each year.

To determine the nominal return on capital in current year prices it is necessary to calculate an opening value of the asset base each year adjusted for inflation and then multiply it by the real pre-tax rate of return.

The opening asset base for each year is equal to the closing book value of the preceding year calculated as follows:

> Closing book value = Opening book value plus current year capex value less depreciation on the opening value (ie excluding full year depreciation on current capex) less partial year depreciation on current year capex plus revaluation of depreciated opening assets.

The depreciation for the first year is calculated on a straight line basis and residual asset life.

The depreciation of current year capex is calculated at half the normal deprecation rate for new assets (based on assuming installation at mid–year).

The depreciation in each year for existing assets (except the first year) is the depreciation for the preceding year (excluding depreciation of current year capex) adjusted for inflation using the current year inflation rate, plus a full year's depreciation on the previous year's capex (after deducting the previous half year of depreciation).

The revaluation of depreciated opening assets is calculated by applying the inflation rate for the current year to the opening asset value less depreciation (excluding depreciation of current year capex).

The return of capital in each year is the sum of the depreciation of existing assets and the depreciation of current year capex.

The return on capital each year is the sum of the product of the real pre–tax return on capital and the opening asset value and half the product of the real pre–tax return on capital and current year capex. This latter component recognises that current year capex is put in place mid–year.

4 ELECTRICITY DISTRIBUTION INDUSTRY PRODUCTIVITY

In this section we use the Fisher TFP index method to calculate the productivity performance of the electricity distribution industry as a whole and for the non–exempt EDBs as a subset group for the 19 years 1996 to 2014. We then examine the input price growth differential term.

4.1 TFP indexing methods

Productivity is a measure of the quantities of outputs produced in proportion to the quantities of inputs used in the production process, and changes in productivity are measured by changes in the ratio of outputs to inputs between two time periods. Since firms usually use several inputs, and may produce several different outputs, the levels of outputs and inputs are measured by indexes. Index numbers are perhaps the most commonly used means of measuring economic variables (Coelli et al. 2005, p. 85). An index number measures a set of related variables relative to a base period. Growth rates for individual outputs and inputs are weighted together using revenue or output cost shares and input cost shares, respectively. In other words, the TFP index is essentially a weighted average of changes in output quantities relative to a weighted average of changes in input quantities.

Total factor productivity is measured by the ratio of an index of all outputs (Q) to an index of all inputs (I):

(4) $$TFP = Q / I$$

Since indexes are defined relative to a base period, the TFP index measures the *proportionate* change in productivity level relative to the base period. The *rate* of change in TFP between two periods is measured by:

(5) $$\dot{TFP} = \dot{Q} - \dot{I}$$

where a dot above a variable represents the rate of change of the variable. TFP indexes have a number of advantages including:

- indexing procedures are simple and robust;
- they can be implemented when there are only a small number of observations;
- the results are readily reproducible;
- they have a rigorous grounding in economic theory;
- the procedure imposes good disciplines regarding data consistency; and
- they maximise transparency in the early stages of analysis by making data errors and inconsistencies easier to spot than using some of the alternative econometric techniques.

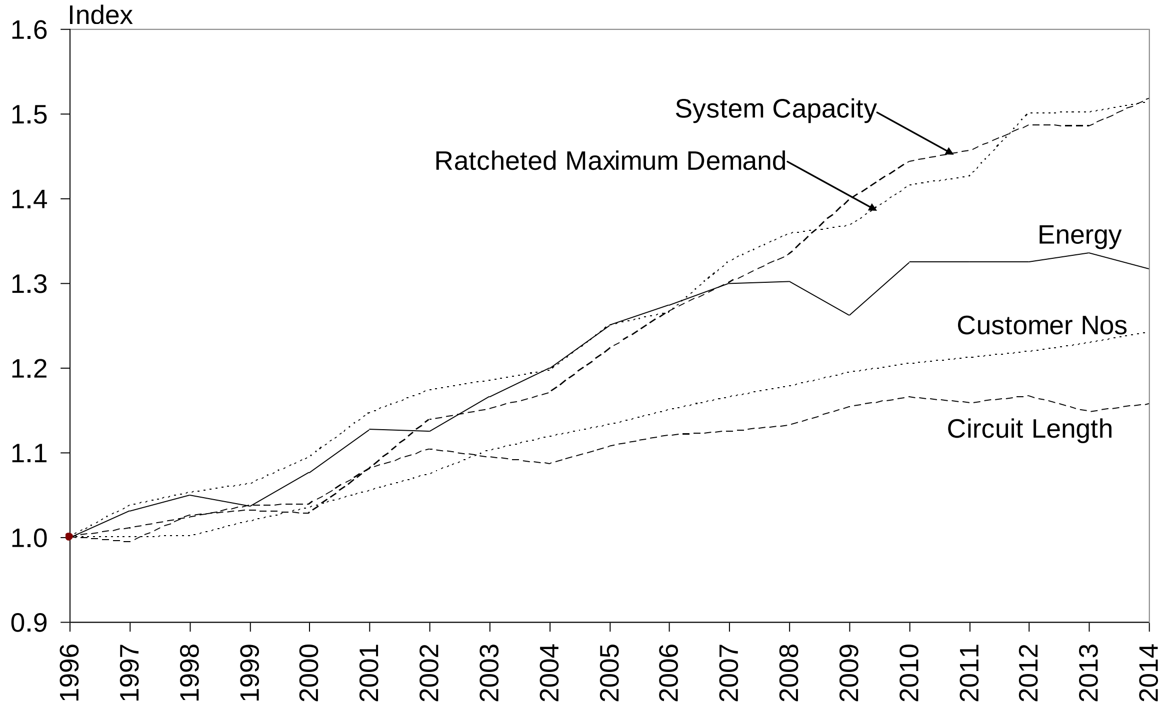
To operationalise TFP measurement we need to combine changes in diverse outputs and inputs into measures of change in total outputs and total inputs. There are alternative index number methods that calculate the weighted average change in outputs or inputs in different ways. Alternative index number methods can be evaluated by examining their economic properties or by assessing their performance relative to a number of axiomatic tests. The index number which performs best against these tests and which is being increasingly favoured by statistical agencies is the Fisher ideal index. The chained version of the Fisher index is used in this study. The formula for the Fisher index is presented in appendix C.

4.2 Distribution industry productivity growth

Output component and total output quantity indexes

As discussed in section 3.2, in this study we examine three different output specifications involving a total of five different output components. The individual output components of energy throughput (in kWh), system capacity (in kWh*kms), customer numbers, ratcheted maximum demand (in MW) and circuit length (in kilometres) are graphed in figure 1 and listed in table 2. Table 2 also reports average annual growth rates for three different periods – 1996 to 2014, 1996 to 2004 and 2004 to 2014.

Figure 1: **Distribution industry output component quantity indexes, 1996–2014**



Source: Economic Insights EDB Database

For the whole 19 year period, the two capacity–related measures of system capacity and ratcheted maximum demand have both grown steadily at an average annual rate of around 2.3 per cent. Growth rates were somewhat higher in the second half of the period compared to the first half.

Energy throughput grew at a similar rate to the two capacity–related measures up to 2007 but since then has grown by an average annual rate of only 0.5 per cent. The global financial crisis led to a fall in energy throughput of 3 per cent in 2009 but this was recovered in 2010. However, since then energy throughput has remained almost stationary due to a range of factors, including improvements in energy efficiency. This contrasts with the Australian situation where energy demand has fallen at an average annual rate of 1.1 per cent since 2008 (AER 2013, p.20). The AER attributes the ongoing decline in electricity demand to:

- commercial and residential customers responding to higher electricity costs by reducing energy use and adopting energy efficiency measures such as solar water heating – new building regulations on energy efficiency reinforce this trend
- subdued economic growth and weaker energy demand from the manufacturing sector, and
- the continued rise in rooftop solar photovoltaic (PV) generation (which reduces demand for electricity supplied through the grid).

Table 2: **Distribution industry output component quantity indexes, 1996–2014**

Year	Energy	Sys Capacity	Customers	Rat.MDemand	Circuit kms
1996	1.000	1.000	1.000	1.000	1.000
1997	1.031	0.994	1.000	1.037	1.010
1998	1.051	1.025	1.001	1.052	1.023
1999	1.037	1.032	1.018	1.063	1.037
2000	1.077	1.028	1.035	1.094	1.038
2001	1.127	1.080	1.055	1.147	1.080
2002	1.125	1.139	1.074	1.173	1.103
2003	1.166	1.151	1.103	1.185	1.095
2004	1.200	1.169	1.119	1.197	1.086
2005	1.251	1.222	1.133	1.250	1.107
2006	1.275	1.266	1.151	1.266	1.119
2007	1.300	1.300	1.165	1.326	1.125
2008	1.303	1.334	1.177	1.358	1.131
2009	1.263	1.397	1.194	1.368	1.153
2010	1.325	1.443	1.204	1.415	1.165
2011	1.325	1.456	1.212	1.425	1.159
2012	1.326	1.486	1.219	1.499	1.166
2013	1.336	1.484	1.229	1.501	1.147
2014	1.317	1.517	1.242	1.514	1.157
Gr 1996–2014	1.53%	2.32%	1.21%	2.30%	0.81%
Gr 1996–2004	2.28%	1.95%	1.40%	2.25%	1.03%
Gr 2004–2014	0.94%	2.60%	1.05%	2.35%	0.63%

Source: Economic Insights EDB Database

The AER (2013, p.21) stated that it expected growth in electricity demand to resume 'in the longer term' with a rising population and moderation of growth in electricity prices. There is thus some evidence that the change in the growth rate of electricity throughput from 2007 onwards represents a significant change in market conditions facing the energy supply industry that can be expected to continue for some years yet. Australia's maximum demand peaked in 2011 and has since fallen by around 6 per cent. New Zealand's peak demand continued rising until 2012 and has fallen by just over 3 per cent since then.

New Zealand EDB customer numbers have grown at an average annual rate of 1.2 per cent over the last 19 years, considerably lower than the growth in the capacity–related outputs and in energy throughput up to 2007. Again, customer numbers growth was somewhat lower in the second half of the period compared to the first.

The output component with the lowest growth rate has been circuit length which has only increased at 0.8 per cent per annum over the last 19 years. Again, this component grew more strongly up to 2002 but at a much more moderate since then.

Table 3: **Distribution industry total output quantity indexes, 1996–2014[a]**

Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	1.006	1.004	1.015
1998	1.013	1.024	1.027
1999	1.028	1.029	1.036
2000	1.037	1.041	1.052
2001	1.069	1.083	1.091
2002	1.090	1.117	1.110
2003	1.098	1.140	1.121
2004	1.101	1.161	1.127
2005	1.119	1.201	1.155
2006	1.134	1.233	1.171
2007	1.143	1.259	1.189
2008	1.152	1.280	1.199
2009	1.172	1.306	1.210
2010	1.183	1.344	1.233
2011	1.183	1.352	1.233
2012	1.190	1.368	1.248
2013	1.184	1.373	1.243
2014	1.195	1.388	1.249
Growth 1996–2014	0.99%	1.82%	1.24%
Growth 1996–2004	1.20%	1.86%	1.49%
Growth 2004–2014	0.82%	1.79%	1.03%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Source: Economic Insights EDB Database

From the examination of the growth rates of the five output components, we can see that output specifications that place more weight on the capacity–related components of system capacity and ratcheted maximum demand will have higher total output growth rates – and therefore higher productivity growth rates – than output specifications that place more weight on slow growing outputs such as customer numbers, circuit length and, since 2007, energy throughput.

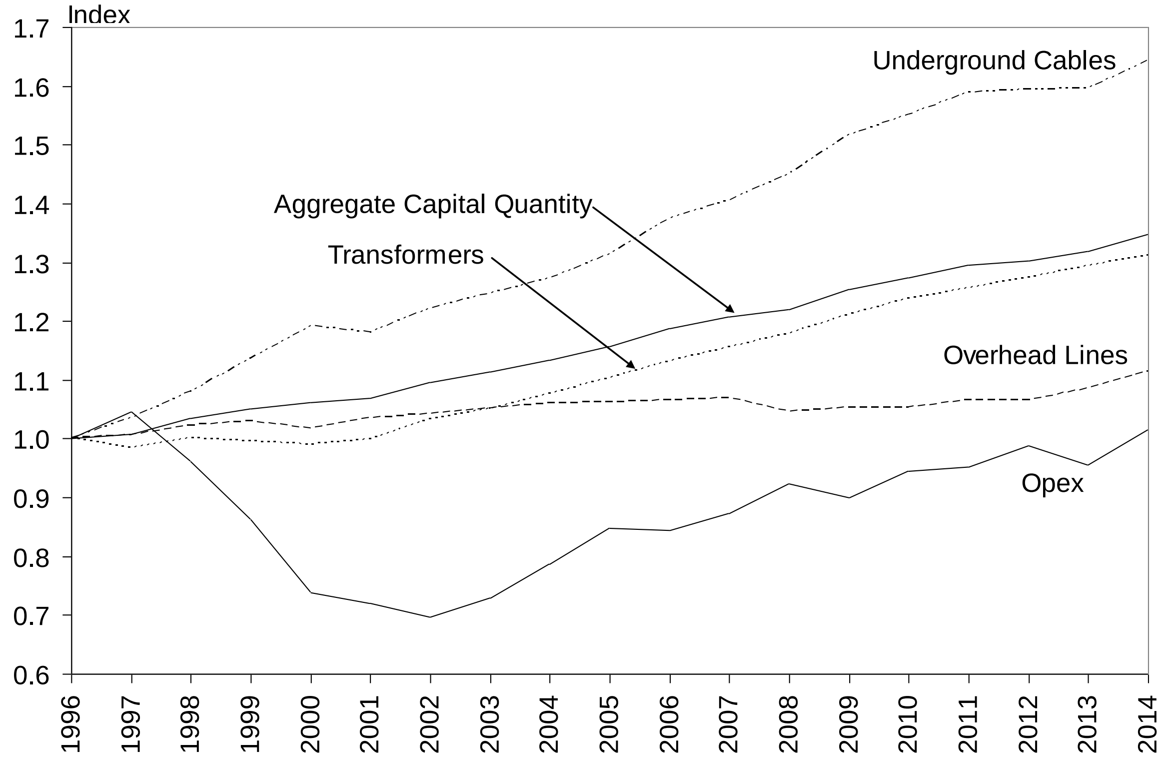
The three total output quantity indexes examined are presented in table 3. The two–output specification is that used by the Commission in its Draft Report. This is the slowest growing of the three output indexes with an average annual growth rate of 1 per cent over the last 19 years and 0.8 per cent over the last decade.

The three–output specification is that used in Economic Insights (2009a) but with updated output cost shares that now place more weight on the system capacity component. As well as system capacity, it includes energy throughput and customer numbers as output components. Approximately half the weight is placed on system capacity and a quarter on each of energy throughput and customer numbers. This output index grows at an average annual rate of a little under 1.8 per cent over the period with little variation between subperiods.

The second slowest growing output index over the whole period is the four–output specification with an average annual growth rate of 1.2 per cent. It grew at an average annual rate of 1 per cent over the last decade. This specification combines four outputs (energy throughput, ratcheted maximum demand, customer numbers and circuit length) and is that used by PEGR (2013a).

Input component and total input quantity indexes

Figure 2: **Distribution industry input component quantity indexes, 1996–2014**



Source: Economic Insights EDB Database

We next turn to the four input measures used in this study. Economic Insights (2009a) used the quantity of opex and the quantities of three capital input components proxied by physical measures – overhead lines, underground cables and transformers – and those measures are again used in this study.

The four input component quantities are presented in figure 2 and table 4 in index form. The quantity of opex input declined by 25 per cent between 1996 and 2002 before growing over the rest of the period to exceed its 1996 level in 2012 before declining slightly in 2013 and then increasing markedly in 2014. For the 19 year period as a whole the average annual opex growth rate was 0.1 per cent although this was made up of growth rate of –3 per cent up to 2004 and 2.6 per cent in the period since 2004.

Capital input quantities have been more consistent in their growth over the 19 year period. Overhead lines quantity grew the least with an average annual growth rate of 0.6 per cent over the whole period and 0.5 per cent over the past decade. Transformer quantity grew by an average annual rate of 1.5 per cent over the whole period although this rate doubled from 0.9 per cent up to 2004 to 2 per cent since 2004. Underground cables quantity grew by far the strongest (albeit from a relatively low base) with an average annual growth rate of 2.8 per cent over the whole period.

Table 4: **Distribution industry input component quantity indexes, 1996–2014**

Year	Opex	Overhead	Underground	Transformers	Capital	Total Inputs
1996	1.000	1.000	1.000	1.000	1.000	1.000
1997	1.045	1.006	1.036	0.984	1.008	1.025
1998	0.961	1.023	1.081	1.002	1.034	1.002
1999	0.863	1.030	1.136	0.995	1.052	0.967
2000	0.738	1.017	1.191	0.990	1.063	0.916
2001	0.720	1.034	1.181	1.000	1.069	0.911
2002	0.697	1.042	1.221	1.032	1.096	0.915
2003	0.730	1.052	1.246	1.051	1.114	0.939
2004	0.787	1.061	1.272	1.076	1.134	0.977
2005	0.849	1.062	1.313	1.104	1.157	1.018
2006	0.845	1.066	1.375	1.131	1.188	1.033
2007	0.872	1.070	1.405	1.156	1.207	1.056
2008	0.923	1.045	1.450	1.179	1.220	1.087
2009	0.900	1.053	1.516	1.212	1.254	1.094
2010	0.945	1.053	1.550	1.238	1.273	1.125
2011	0.952	1.065	1.589	1.256	1.295	1.141
2012	0.989	1.066	1.595	1.274	1.303	1.162
2013	0.956	1.085	1.596	1.294	1.318	1.155
2014	1.015	1.114	1.643	1.312	1.348	1.198
Gr 1996–2014	0.08%	0.60%	2.76%	1.51%	1.66%	1.01%
Gr 1996–2004	–3.00%	0.74%	3.00%	0.92%	1.57%	–0.29%
Gr 2004–2014	2.55%	0.49%	2.56%	1.98%	1.73%	2.04%

Source: Economic Insights EDB Database

The aggregate of the three capital input quantities (weighted by their respective amortisation annual user costs) grew at an average annual rate of 1.7 per cent with little variation between subperiods. The three components receive between 30 and 36 per cent weight each in the aggregation process with transformers and other capital receiving the higher weight.

Total input use increased at an average annual rate of around 1 per cent over the 19–year period although this was made up of a growth rate of –0.3 per cent up to 2004 and of over 2 per cent over the last decade.

Industry TFP growth rates

We now combine the total output and total input quantity indexes discussed above to form EDB industry TFP indexes. Table 5 and figure 3 present TFP indexes based on the three different output specifications.

Table 5: **Distribution industry total factor productivity indexes, 1996–2014[a]**

Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	0.981	0.980	0.991
1998	1.011	1.022	1.025
1999	1.064	1.064	1.072
2000	1.132	1.136	1.149
2001	1.173	1.189	1.199
2002	1.191	1.221	1.214
2003	1.169	1.214	1.193
2004	1.127	1.188	1.154
2005	1.098	1.180	1.134
2006	1.098	1.194	1.134
2007	1.082	1.193	1.126
2008	1.060	1.177	1.103
2009	1.071	1.193	1.106
2010	1.051	1.194	1.096
2011	1.037	1.186	1.081
2012	1.024	1.178	1.074
2013	1.025	1.189	1.076
2014	0.997	1.158	1.043
Growth 1996–2014	–0.01%	0.82%	0.23%
Growth 1996–2004	1.49%	2.16%	1.79%
Growth 2004–2014	–1.22%	–0.26%	–1.01%

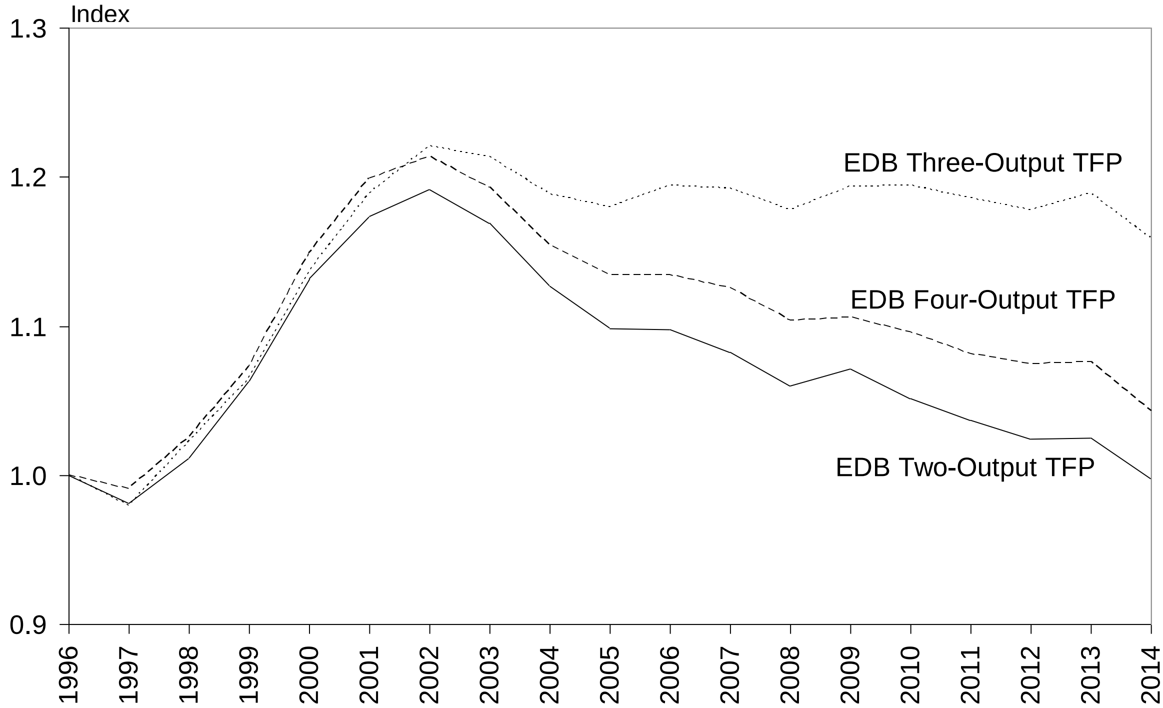
[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates

The first column of results in table 5 use the Commission's two–output specification covering customer numbers and line length. Because these are the two slowest growing outputs then TFP growth is correspondingly the lowest using this measure. TFP was virtually flat for the 19 year period as a whole. EDB industry TFP increased at an average annual growth rate of 1.5 per cent up to 2004 but has declined after this to grow at an average annual rate of –1.2 per cent over the last decade.

The second column of results uses the output and input specification used in Economic Insights (2009a). EDB industry TFP increased strongly up to 2004 at an average annual growth rate of 2.2 per cent but has declined slightly after this to grow at an average annual rate of –0.3 per cent over the last decade. For the 19 year period as a whole average annual TFP growth was 0.8 per cent.

The third column of results present the four output specification used in PEGR (2013a). Because our cost function estimation led to a high weight of 47 per cent being placed on the slowest growing output component of circuit length, this specification produces a lower TFP average annual growth rate of 0.2 per cent for the 19 year period as a whole, made up of an average annual growth rate of 1.8 per cent for the period up to 2004 and of –1 per cent for the decade since then.

Figure 3: **Distribution industry total factor productivity indexes, 1996–2014**



[a] Two–Output specification: Customer nos (46%), Circuit length (54%)

Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)

Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)

Output cost shares in brackets

Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates

Industry opex partial productivity growth rates

EDB opex partial productivity indexes and average annual growth rates are presented in table 6 for the three different output specifications.

The opex partial productivity indexes exhibit a broadly similar pattern to that of TFP except that there is faster growth in the first half of the period before a decline over the last decade. Because opex declined substantially between 1996 and 2002 while total input use only declined by a small amount over the same period, opex partial productivity average annual growth rates are in the range of approximately 4 to 5 per cent for the period up to 2004 while TFP growth rates were only around 1.5 to 2 per cent for this period. For the period since 2004, opex partial productivity average annual growth using the three–output specification (as used in Economic Insights 2009a) was –0.8 per cent. However, without the effects of an 8 per cent increase in opex in 2014, the average annual growth rate fo opex partial productivity in the decade to 2013 was –0.3 per cent. Average annual opex partial productivity growth rates using the two–output and four–output specifications were –1.7 and –1.5 per cent, respectively, for the past decade. Again, without the effect of the large increase in opex in 2014, these growth rates were –1.4 and –1.1 per cent, respectively, for the decade to 2013.

Table 6: **Distribution industry opex partial productivity indexes, 1996–2014**[a]

Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	0.962	0.960	0.971
1998	1.054	1.065	1.068
1999	1.192	1.193	1.201
2000	1.405	1.410	1.425
2001	1.485	1.504	1.516
2002	1.563	1.601	1.592
2003	1.505	1.562	1.536
2004	1.399	1.475	1.432
2005	1.318	1.416	1.361
2006	1.342	1.460	1.386
2007	1.310	1.443	1.363
2008	1.248	1.386	1.299
2009	1.302	1.450	1.344
2010	1.252	1.422	1.305
2011	1.242	1.420	1.295
2012	1.203	1.383	1.262
2013	1.238	1.436	1.300
2014	1.177	1.367	1.230
Growth 1996–2014	0.91%	1.74%	1.15%
Growth 1996–2004	4.20%	4.86%	4.49%
Growth 2004–2014	–1.73%	–0.76%	–1.52%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)

Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)

Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)

Output cost shares in brackets

Source: Economic Insights estimates

Industry capital partial productivity growth rates

EDB capital partial productivity indexes and average annual growth rates are presented in table 7 for the three different output specifications using the physical quantities proxy for capital input quantity.

Table 7: **Distribution industry capital partial productivity indexes, 1996–2014[a]**

Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	0.998	0.996	1.007
1998	0.979	0.990	0.993
1999	0.977	0.978	0.985
2000	0.976	0.979	0.990
2001	1.000	1.013	1.021
2002	0.994	1.019	1.013
2003	0.986	1.023	1.006
2004	0.971	1.024	0.994
2005	0.966	1.038	0.998
2006	0.955	1.039	0.986
2007	0.947	1.043	0.985
2008	0.944	1.049	0.983
2009	0.935	1.041	0.965
2010	0.929	1.056	0.969
2011	0.914	1.044	0.952
2012	0.913	1.050	0.958
2013	0.899	1.042	0.943
2014	0.887	1.029	0.927
Growth 1996–2014	–0.67%	0.16%	–0.42%
Growth 1996–2004	–0.37%	0.29%	–0.08%
Growth 2004–2014	–0.91%	0.06%	–0.70%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Source: Economic Insights estimates

The capital partial productivity indexes have generally had less movement away from their initial values than have the opex partial productivities. Capital partial productivity average annual growth rates are in the range of 0.2 to –0.7 per cent for the whole 19 year period. For the period up to 2004, the range of capital partial productivity average annual growth rates was 0.3 to –0.4 per cent and over the last decade it has been 0.1 to –0.9 per cent. Using the two–output specification (as used by the Commission in its Drfat Report), the capital partial productivity average annual growth rate has generally been in the –0.4 to –0.9 per cent range.

4.3 Non–exempt distribution productivity growth

Non–exempt distribution accounted for around 80 per cent of electricity distribution industry throughput, maximum demand and customer numbers in 2014. It accounted for just over 80 per cent of the industry's underground cable length but just under 70 per cent of its overhead line length.

Table 8: **Non–exempt EDB total factor productivity indexes, 1996–2014[a]**

Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	0.977	0.973	0.987
1998	1.010	1.017	1.025
1999	1.065	1.058	1.073
2000	1.153	1.145	1.169
2001	1.192	1.194	1.220
2002	1.224	1.241	1.248
2003	1.203	1.231	1.227
2004	1.149	1.194	1.177
2005	1.114	1.179	1.153
2006	1.121	1.200	1.159
2007	1.112	1.206	1.158
2008	1.095	1.193	1.140
2009	1.117	1.215	1.151
2010	1.099	1.219	1.144
2011	1.085	1.208	1.129
2012	1.071	1.198	1.121
2013	1.070	1.205	1.121
2014	1.037	1.173	1.085
Growth 1996–2014	0.20%	0.88%	0.45%
Growth 1996–2004	1.74%	2.21%	2.04%
Growth 2004–2014	–1.03%	–0.18%	–0.82%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates

Non–exempt TFP indexes and growth rates for the three different output specifications are reported in table 8. Non–exempt EDB output has grown at a similar rate to distribution industry output over both the last 19 years and the last decade using the two–output specification used by the Commission in its Draft Report. However, non–exempt input use has grown at an average annual rate of around 0.2 less than that for the industry over the same periods. This has led to non–exempt TFP average annual growth being around 0.2 per cent higher than that for the industry as a whole.

Non–exempt EDB opex partial productivity indexes and average annual growth rates are reported in table 9 for each of the three output specifications used in this report. The average difference between non–exempt and distribution industry growth rates across the three opex partial productivity measures is around 0.1 per cent.

Although not presented in tabular form, non–exempt capital partial productivity grew at an average annual rate of 0.2 per cent higher than that for the distribution industry as a whole across the different partial productivity measures and each of the time periods examined.

The non–exempt EDBs in aggregate have thus exhibited marginally stronger TFP and partial productivity growth across each of the three time periods examined – 1996 to 2014, 1996 to 2004 and 2004 to 2014 – than has the distribution industry as a whole. However, the difference in growth rates is not large and decisions regarding the setting of the X factor and what opex partial productivity growth rate to use in forming opex forecasts for the next regulatory period should be relatively robust to whether results for the industry as a whole or non–exempt EDBs in aggregate are used.

Table 9: **Non–exempt EDB opex partial productivity indexes, 1996–2014[a]**

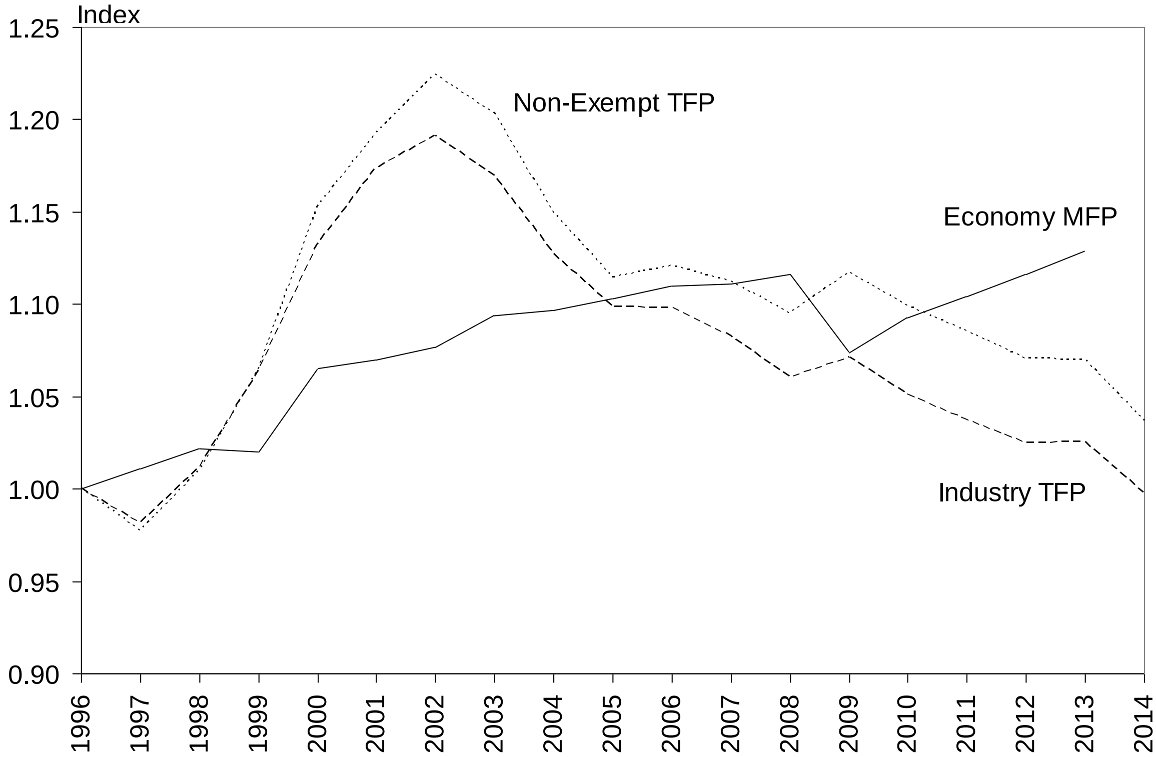
Year	Two–Output Specification	Three–Output Specification	Four–Output Specification
1996	1.000	1.000	1.000
1997	0.950	0.946	0.959
1998	1.053	1.060	1.068
1999	1.193	1.186	1.203
2000	1.459	1.449	1.480
2001	1.504	1.507	1.539
2002	1.621	1.643	1.652
2003	1.563	1.599	1.593
2004	1.418	1.473	1.452
2005	1.317	1.393	1.362
2006	1.355	1.451	1.401
2007	1.345	1.459	1.400
2008	1.282	1.397	1.335
2009	1.371	1.490	1.412
2010	1.320	1.464	1.373
2011	1.307	1.455	1.360
2012	1.248	1.396	1.307
2013	1.277	1.439	1.338
2014	1.203	1.360	1.258
Growth 1996–2014	1.03%	1.71%	1.28%
Growth 1996–2004	4.37%	4.84%	4.67%
Growth 2004–2014	–1.65%	–0.80%	–1.44%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Source: Economic Insights estimates

Non–exempt EDB TFP, distribution industry TFP and economy market sector multifactor productivity (MFP) are plotted in figure 4. The two aggregate EDB TFP indexes use the two–output specification used in the Commission's Draft Report. The two electricity distribution TFP indexes increase faster than economy–wide MFP in the period from 1996 to 2002 but have declined since whereas economy–wide MFP has generally increased, except for the year of the global financial crisis.

In the decade since 2004, the economy–wide MFP has increased at an average annual growth rate of 0.3 per cent while EDB TFP has grown at an average annual rate of –1 per cent for non–exempt EDBs and –1.2 per cent for the distribution industry as a whole.

Figure 4: **Non–exempt EDB, EDB industry and economy TFP indexes, 1996–2014[a]**



[a] EDB TFP uses the two–output specification: Customer nos (46%), Circuit length (54%), output cost shares in brackets.
Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates and SNZ (2014)

Over the 19 year period as a whole, economy–wide MFP has grown at an average annual rate of 0.7 per cent while TFP for non–exempt EDBs has grown at 0.2 per cent and for the distribution industry as a whole at zero per cent.

4.4 Overseas EDB productivity growth

It is useful to compare the trend TFP growth rates presented in this report with comparable results that have been presented for overseas jurisdictions. This provides a worthwhile means identifying any anomalies. The Act also states that the Commission can draw on information on EDB productivity growth from comparable countries in setting the rate of change of prices.

Australian EDBs present a ready point of comparison for NZ EDBs. However, there have been no Australian EDB productivity studies published since those reported in Economic Insights (2009a). The AER is currently undertaking an extensive data collection and economic benchmarking exercise which will likely include EDB productivity growth results. At the time of preparation of this report, the Australian EDB results are not publicly available. However, as noted in section 4.2, Australian energy throughput and maximum demands have both declined significantly from their peaks around 2009. Combined with increases in both opex and capex allowances included in recent regulatory reviews, this means Australian EDB productivity is more likely to have declined than improved over the last several years.

PEGR (2013a,b) has recently reported productivity growth results for the Ontario electricity distribution industry. These results are of particular interest since the Ontario industry shares many features with the New Zealand industry including a large number of EDBs made up of a small number of larger EDBs and many small to very small EDBs. The methodology used to measure productivity growth in PEGR (2013a,b) is also broadly similar to that used in the current study. For the period 2002 to 2012 PEGR (2013b) found that the Ontario electricity distribution industry had an average annual TFP growth rate of –0.3 per cent. Excluding the year 2012 which was thought to be influenced by a number of data reporting changes, the average annual TFP growth rate for 2002 to 2011 was still only 0.2 per cent. These growth rates are of similar magnitude to those obtained in the current study.

While less comparable to New Zealand, evidence on recent productivity growth for the United States electricity distribution industry is mixed. PEGR (2013c) reports average annual TFP growth rates for US EDBs in different parts of the country ranging from 0.6 per cent to 1.1 per cent for the period 2002 to 2011 and average annual opex partial productivity growth rates of around 1.5 per cent. However, while a report by Makholm, Ros and Case (2011) reported an average annual TFP growth rate of 0.9 per cent based on a sample of 72 US EDBs over a nearly 40 year period, the average annual TFP growth rate over the decade to 2009 (the most recent year reported) was around –1.1 per cent.

There is limited comparable information on productivity growth rates available for United Kingdom EDBs. However, recently Oxera (2013, p.6) found that 'the net ongoing efficiency achieved by the DNOs [distribution network operators] in recent years has not been statistically significant, indicating that the technology (net of any input price inflationary effects) has been largely constant'. This would be consistent with a zero growth rate for EDB TFP, assuming the EDBs were operating efficiently.

Our review of studies of the recent productivity performance of EDBs in countries broadly comparable to New Zealand finds that reported EDB productivity growth rates are generally similar to those found in the current study although there is some evidence of ongoing positive productivity growth in the more mature US industry in recent years.

4.5 Input price growth

The remaining components of equation (2) from section 3.2 we require information on are the input price growth terms for the electricity distribution industry and the economy as a whole. As demonstrated in Economic Insights (2009b), where industry assets have sunk cost characteristics the appropriate industry input price term is the cost share weighted sum of the change in the opex price and unit changes in amortisation charges. The amortisation charges used in this study have been calculated on the basis of ex ante financial capital maintenance as would be found in building blocks regulation.

We adopt a broadly similar approach to measuring electricity distribution industry input prices as that used in Economic Insights (2009a). Relevant indexes are presented in table 10.

Table 10: **Distribution industry and economy–wide input price indexes, 1996–2014**

	Electricity Distribution Industry			Economy–Wide		
Year	LCI	Amortisation	Input Price	CPI	MFP	Input Price
1996	1.000	1.000	1.000	1.000	1.000	1.000
1997	1.020	1.014	1.017	1.022	1.011	1.032
1998	1.043	1.029	1.035	1.033	1.022	1.055
1999	1.062	1.036	1.049	1.042	1.020	1.062
2000	1.077	1.029	1.056	1.045	1.065	1.111
2001	1.095	1.041	1.078	1.076	1.070	1.149
2002	1.116	1.060	1.101	1.103	1.077	1.185
2003	1.141	1.076	1.119	1.133	1.094	1.235
2004	1.167	1.106	1.144	1.150	1.097	1.257
2005	1.195	1.120	1.167	1.180	1.103	1.296
2006	1.231	1.155	1.205	1.217	1.110	1.344
2007	1.270	1.211	1.253	1.256	1.111	1.388
2008	1.311	1.276	1.304	1.288	1.116	1.429
2009	1.359	1.327	1.361	1.338	1.074	1.428
2010	1.386	1.386	1.396	1.363	1.093	1.480
2011	1.410	1.435	1.432	1.403	1.104	1.537
2012	1.438	1.504	1.478	1.449	1.116	1.604
2013	1.464	1.553	1.512	1.462	1.129	1.637
2014	1.489	1.577	1.537	1.481	1.143	1.678
Gr 96–14	2.21%	2.53%	2.39%	2.18%	0.74%	2.88%
Gr 96–04	1.93%	1.26%	1.68%	1.75%	1.16%	2.86%
Gr 04–14	2.43%	3.55%	2.95%	2.53%	0.41%	2.89%

Source: Economic Insights EDB Database and Statistics New Zealand

For the economy as a whole we form a total input price index by adopting the assumption used in PEG (2014) that the change in economy–wide input prices can be approximated by the sum of changes in economy–wide MFP and the consumer price index.

We form the overall input price index for the electricity distribution industry by aggregating the labour price and the amortisation price of capital. We focus on labour and capital prices to be consistent with the net productivity framework used in the National Accounts and the SNZ Multifactor Productivity Index. To be consistent with the sunk cost nature of electricity distribution assets while also allowing for ex ante FCM, we use the amortisation price for capital inputs rather than the traditional user cost formula. We do this by dividing the distribution industry amortisation values for pre–tax amortisation by the capital quantity index. The capital quantity index was formed by aggregating overhead lines MVA–kilometres, underground cable MVA–kilometres and transformer kVAs using the shares of the three capital inputs in the 2004 ODV given in the 2008 IDD. For the industry as a whole these shares are around 30 per cent for overhead lines, 34 per cent for underground cables and 36 per cent for transformers and other capital.

From table 10 we see that average annual growth rate in EDB opex prices has been around 0.5 per cent lower than that for the economy–wide increase in labour prices over the 19 year period as a whole. However, for the period up to 2004, annual EDB input price growth was around 1.2 per cent less than economy–wide input price growth. This early pattern has reversed over the last decade where EDB input prices have had a marginally higher average annual growth rate than economy–wide input prices.

5 RECOMMENDATIONS

The objective of this report has been to provide information to inform the Commission's decisions regarding the 2014 default price–quality path reset. The reset will involve either resetting EDB starting prices taking account of current and future profitability or, alternatively, rolling over the prices applying in the last year of the preceding regulatory period. If prices are reset, this will be done by the application of the building blocks methodology. The information contained in this report relevant to the application of building blocks is:

- the long–run productivity growth rate for the electricity distribution industry, and
- opex and capital partial productivity growth rates for the electricity distribution industry.

If prices are rolled over from the last year of the preceding regulatory period, the Commission has indicated that the rate of change of prices will be determined using information on productivity and input price differentials between the electricity distribution industry and the economy as a whole. This is the approach generally used in productivity–based regulation.

Our recommendations on the relevant components for the building blocks and productivity–based approaches are presented in the following sections.

5.1 Building blocks component recommendations

X Factor

As described in section 2.2, in building blocks the starting prices and the rate of change (or X factor) are set as a pair to equate the net present values of forecast revenue and forecast costs (or the 'revenue requirement'). Changes in the X factor would be offset by changes in starting prices to maintain this equality. While there is an infinite number of starting price and X factor combinations that will achieve this equality, the Act states that the X factor should be based on the long run productivity improvement achieved by EDBs in New Zealand and/or comparable countries.

As shown in section 4.4, EDB productivity growth rates in New Zealand have been broadly similar to those found in comparable countries such as Canada, those likely to be found in Australia and those reported in larger countries such as the US and the UK. Consequently, we concentrate on New Zealand productivity growth rates in this section.

The next issue to resolve is what time period constitutes the 'long run'. We have observations for New Zealand spanning the past 19 years. Normally one would seek as long a time period as possible to form an estimate of a long run growth rate. This implicitly assumes that growth occurs and continues in a linear fashion and that there are no fundamental underlying changes occurring. However, productivity growth may not be linear and may instead converge over time to a given (lower) rate. This could occur if inefficiencies relative to current technological possibilities are progressively eliminated so that productivity growth eventually becomes constrained by the rate of underlying technical change. And significant changes in underlying market conditions may lead to a change or 'break' in the achievable rate of productivity growth.

There is some evidence from a range of comparable countries that a significant change in market conditions facing the energy supply industry has occurred recently. In New Zealand electricity throughput grew at an average annual rate of 2.4 per cent between 1996 and 2007 but since 2007 it has grown at less than 0.5 per cent. While the global financial crisis reduced demand for electricity in 2009, it recovered in 2010 but has remained virtually static since then. In Australia, electricity demand reversed in 2008 and has fallen at an average annual rate of 1.1 per cent since then. A similar pattern has been observed in Ontario (PEGR 2013a,b). Maximum demand also peaked in Australia in 2009 and has fallen by a total of 3 per cent in New Zealand since 2012.

The AER (2013, p.20) has attributed this reversal of electricity demand to higher prices, more energy efficient appliances and, importantly, more energy efficient buildings, and the increasing penetration of rooftop solar PV panels. In the US, Barclay's Bank has cautioned utility investors with the following[4]:

> 'In the 100+ year history of the electric utility industry, there has never before been a truly cost–competitive substitute available for grid power. Over the next few years, however, we believe that a confluence of declining cost trends in distributed solar photovoltaic (PV) power generation and residential-scale power storage is likely to disrupt the status quo. … The cost of solar plus storage for residential consumers is already competitive with the price offered by the traditional utility grid in Hawaii. … The sun–drenched states of California and Arizona are only a couple of years behind, as is solar friendly New York.'

The Australian Energy Market Operator (AEMO 2014, p.ii) states that it expects residential and commercial electricity consumption to grow at an average annual rate of –0.5 per cent through to 2016 and for electricity consumption to be relatively flat after that. AEMO (2014, p.iv) also expects that only Queensland and NSW will return to their historic maximum demand levels within the next decade while the southern states may take two decades to return to their historic maximums. It thus looks likely that the main source of output growth for Australian EDBs over the next regulatory period will be from ongoing increases in customer numbers resulting from population growth.

The next issue to consider is how we calculate growth rates. In previous reports for the Commission we have used the trend or regression–based method which smoothes the underlying data. In Economic Insights (2014a) and in previous sections of this report, we have used the endpoint–to–endpoint logarithmic growth rate method which is more convenient to implement and which generally provides a reasonable approximation to the underlying growth rate, except where there is an unusual movement at either end of the series. In extending the time–series to 2014, we now find an unusual increase of 8 per cent in the opex series reported in 2014. Anecdotal reasons advanced for this sudden increase in opex in 2014 include a prevalence of adverse weather events in 2014 compared to more benign weather in 2013. However, there is also an incentive for EDBs to increase their opex disproportionately in 2014 in anticipation of the Commission's approach to the reset. To

[4] Cited in ABC News, *Technology, not regulation, will kill coal fired power*, http://www.abc.net.au/news/2014-06-04/technology-not-regulation-will-kill-coal-fired-power/5500356

reduce the potential impact of gaming and unusual events in 2014 on measured growth rates, we believe it is appropriate to use trend growth rates in arriving at our recommendations.

As noted in section 3.2, a point consistently raised in submissions on productivity measurement aspects of the Commission's draft report was that Economic Insights (2014a) did not include the two–output specification used by the Commission in other parts of its rate of change modelling of EDB opex requirements under the building blocks approach. In this report we have reported productivity results using the two–output specification (covering customer numbers and circuit length) used by the Commission, the three–output specification we have used in previous reports for the Commission (covering energy, system capacity and customer numbers), and the four–output used by PEG (2013) in benchmarking work for the Ontario regulator (covering energy, ratcheted maximum demand, customer numbers and circuit length).

Productivity trend annual growth rates using these three output specifications are presented in table 11.

Table 11: **Distribution industry productivity growth rates, 1996–2014, per cent pa[a]**

	1996–2014	1996–2004	2004–2014
TFP			
2 outputs	–0.18%	2.38%	–1.08%
3 outputs	0.81%	3.00%	–0.13%
4 outputs	0.08%	2.63%	–0.88%
Opex Partial Productivity			
2 outputs	0.45%	6.16%	–1.40%
3 outputs	1.44%	6.77%	–0.45%
4 outputs	0.70%	6.41%	–1.20%
Capital Partial Productivity			
2 outputs	–0.63%	–0.17%	–0.88%
3 outputs	0.36%	0.45%	0.08%
4 outputs	–0.38%	0.08%	–0.68%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Input specification: Opex, Overhead lines, Underground cables, Transformers and other capital
Source: Economic Insights estimates

Because the Commission's two–output specification covering customer numbers and line length includes the two slowest growing outputs then TFP growth is correspondingly the lowest using this measure.

Under building blocks regulation there is no need for the same output specification to be used in the rate of change calculation of future opex requirements and for the overall X factor. This is because under building blocks regulation the X factor is simply a smoothing device for the price path over the regulatory period and the initial price reset is usually used to equate the net present values of forecast revenues and the revenue requirement subject to the chosen X factor. Hence, while the Commerce Act stipulates that the X factor should be based on the long–run average productivity improvement rate achieved by EDBs, there is no requirement for the productivity specification to be the same as that used in the opex rate of change formula. However, for simplicity and to avoid confusion, we recommend that the two–output specification also be used in the X factor calculation. Likewise, there is no real need for the time periods covered to be identical either but, for simplicity, we will use the period 2004–2014 for all calculations.

For the building blocks X factor we recommend the two–output TFP trend growth rate for the period 2004–2014 of –1 per cent (rounded down for simplicity). In building blocks there is no need to include the differentials that are used in pure productivity–based regulation and hence it is appropriate to simply use the trend estimate of TFP growth itself.

Opex partial productivity growth

The other important productivity component in the building blocks approach is the rate of opex productivity growth to include in rolling forward the opex component of the revenue requirement. The Commission (2014a) has indicated it intends to roll opex forward by the sum of the forecast growth rate in opex prices plus the forecast growth rate in output (or scale effects) minus the forecast growth rate in opex partial productivity.

From table 11 we see that a similar situation exists with electricity industry opex partial productivity as with TFP. There was very strong trend annual growth in opex partial productivity of over 6 per cent from 1996 to 2004, mainly due to a reduction in the quantity of opex inputs of over 30 per cent in total. In the past decade, however, opex partial productivity trend annual growth has been –1.4 per cent as opex quantities have grown strongly.

For New Zealand, output growth has been quite steady over time, until recently. The outputs the Commission has chosen in its two–output specification (ie customer numbers and line length) are particularly steady growers with customer numbers approximately moving in line with population growth and line length increasing at around two thirds that rate. Opex quantity growth, by contrast, has varied widely. It decreased steadily from 1996 until around 2002 and has grown almost as quickly since then. This can be seen clearly from table 12 and figure 5.

Table 12: **EDB opex PFP driver growth rates, 1996–2014, per cent pa**[a]

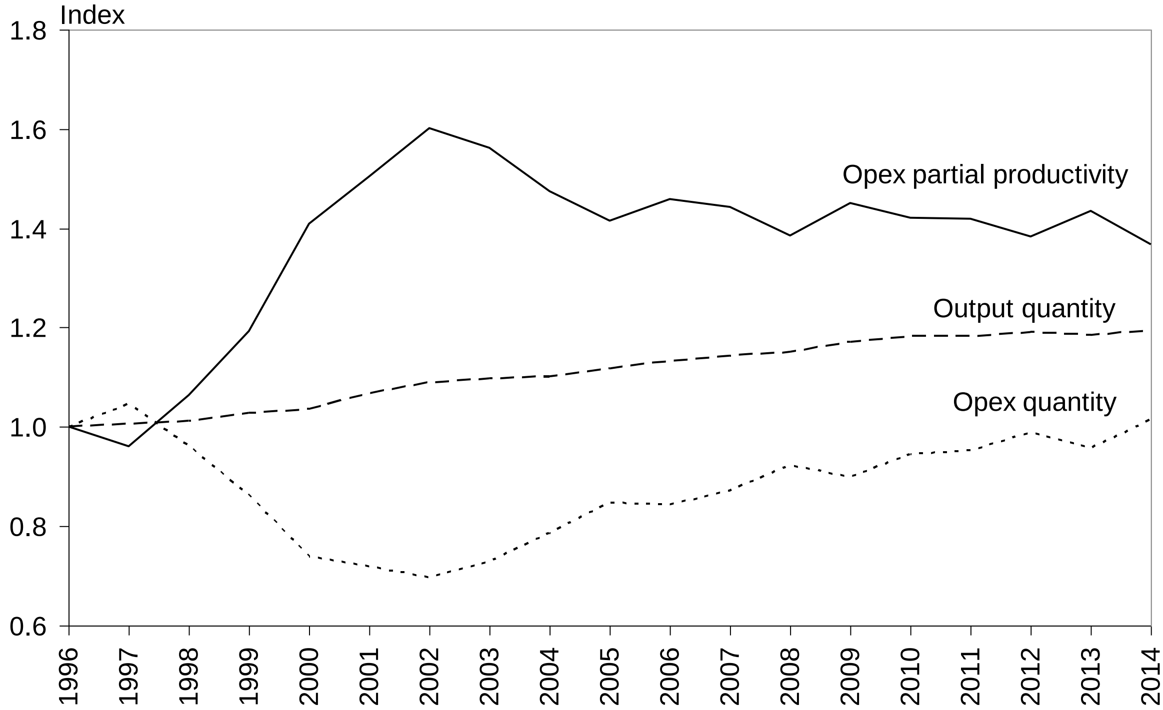
	1996–2014	1996–2004	2004–2014
Output Quantity Growth			
2 outputs	0.99%	1.20%	1.03%
3 outputs	1.82%	1.86%	2.23%
4 outputs	1.24%	1.49%	1.29%
Opex Quantity Growth	0.08%	-3.00%	2.55%

[a] Two–Output specification: Customer nos (46%), Circuit length (54%)
Three–Output specification: Energy (22%), System capacity (kVA*kms) (49%), Customer nos (29%)
Four–Output specification: Energy (15%), Ratcheted maximum demand (15%), Customer nos (23%), Circuit length (47%)
Output cost shares in brackets
Source: Economic Insights estimates

It can be seen that high growth in the quantity of opex compared to much more modest growth in output over the last decade is the driver of the negative opex partial productivity growth rate. Since the Commission has chosen the slowest growing measure of output, correspondingly opex partial productivity growth rate using this measure is the most negative.

EDB submissions on the Commission's Draft Report quote increases in regulatory responsibilities as one of the main drivers of the ongoing rapid increase in opex. A similar thing has happened in Australia where the distribution businesses have continually mounted cases for 'step changes' at each review and have been reasonably successful in having these approved in the past. This then distorts the measured opex partial productivity growth rate which is reduced because like is no longer being compared with like. If step changes have not been explicitly identified, it is often not possible to exclude the effects of step changes from historic data.

Figure 5: **EDB opex PFP components, 1996–2014**[a]



[a] EDB TFP uses the two–output specification: Customer nos (46%), Circuit length (54%), output cost shares in brackets.
Source: Economic Insights estimates

Including a negative opex PFP growth rate in the opex rate of change formula also has potentially bad incentive properties. We have concerns with the incentive effects of including negative opex partial productivity growth rates in the rate of change formula – to some extent this would be akin to rewarding the EDBs for having previously overestimated future output growth and now entrenching productivity decline as the new norm. Such a situation is also arguably at odds with the workably competitive market assumptions in the Commerce Act. One would not expect to see ongoing productivity decline in a workably competitive market.

A situation of declining opex partial productivity is very much an unusual situation as one normally expects to see a situation of positive technical progress rather than technical regress over time. While we acknowledge the distinction between the underlying state of technological knowledge in the electricity distribution industry and the impact of cyclical factors that may lead to periods of negative measured productivity growth, the latter would be expected to be very much the exception, step change issues aside.

All else equal, failure to allow for the effect of past reset opex step changes in subsequent resets will lead to EDBs being over–remunerated as the measured opex productivity growth rate will underestimate the actual opex productivity growth rate. The opex partial productivity growth rate used in the rate of change formula needs to reflect productivity growth excluding step changes or else, if measured opex productivity is used, negative step changes may be required to equate the net present value of the actual opex requirements and the allowance resulting from application of the rate of change formula. To avoid negative step changes, this points to the use of a forecast productivity growth rate higher than measured from historic data spanning more than one regulatory period.

The recent opex PFP growth rate using the two–output specification is –1.4%. Mechanistic extrapolation of the recent rate would see a negative opex PFP growth rate being used in the opex rate of change used to forecast future opex requirements. However, this would have potentially adverse incentive effects and could lead to EDBs being over– remunerated due to progressive inclusion of step changes in base year opex. Our recommendation is for a zero opex PFP growth rate to be used in the rate of change formula.

Capital partial productivity growth

While capital partial productivity is unlikely to be used in the building blocks approach (which focuses on capex whereas productivity measurement only provides overall capital stock productivity information), from table 11 we see that capital partial productivity growth has generally shown less variation than either TFP or opex partial productivity growth. Over the past decade estimates of the average annual capital partial productivity growth rate range from 0.1 to –0.9 per cent. For similar reasons to those we are recommending zero as the appropriate rate for opex partial productivity forecasts, we recommend that the capital partial productivity forecast, if used, should also be zero.

5.2 Productivity–based regulation recommendations

If the Commission opts to roll over EDB prices from the last year of the preceding regulatory period, it has indicated it will do so using a productivity–based regulation approach to setting the X factor. The formula for the X factor under productivity–based regulation taking account of sunk costs and financial capital maintenance was given in equation (2) and is repeated here for convenience:

(6) $X \equiv [\Delta TFP - \Delta TFP_E] - [\Delta W - \Delta W_E]$

= TFP differential growth rate term – input price differential growth rate term.

where the industry capital price included is the unit amortisation charge. Equation (6) is often referred to as the 'differential of differentials' formula. It should be emphasised the X factor is derived in a very different way in productivity–based regulation compared to building blocks regulation.

The components required to populate equation (6) were derived in section 4 and trend growth rates are presented in table 13 below.

The first term in (6) involves the difference in TFP growth rates between the electricity distribution industry and the economy. Using the two–output TFP measure for EDBs and the SNZ MFP series (which only runs to 2013) for economy–wide productivity we obtain a productivity differential term of –1.2 per cent.

Table 13: **Productivity–based regulation differentials, 1996–2014, per cent pa**[a]

	1996–2014	1996–2004	2004–2014
EDB Two–Output TFP Growth (a)	–0.18%	2.38%	–1.08%
Economy MFP Growth[b] (b)	0.61%	1.27%	0.14%
Productivity Differential (c) = (a) – (b)	–0.79%	1.12%	–1.22%
EDB Input Price Growth (d)	2.55%	1.63%	3.14%
Economy Input Price Growth[b] (e)	2.92%	2.94%	2.87%
Price Differential (f) = (d) – (e)	–0.38%	–1.31%	0.27%
X Factor (g) = (c) – (f)	–0.41%	2.43%	–1.49%

[a] EDB TFP uses the two–output specification: Customer nos (46%), Circuit length (54%), output cost shares in brackets.
[b] Trend calculated to 2013 as 2014 MFP data not yet released.
Source: Economic Insights estimates and Statistics New Zealand

It should be noted that the calculations in table 13 bias the productivity differential downwards as the industry measure is a gross TFP measure while the economy–wide MFP measure is a net or value added–based productivity measure. A gross productivity measure has materials and services inputs in the denominator along with labour and capital inputs. A net productivity measure, on the other hand, deducts materials and services inputs from output in numerator and has only labour and capital in the denominator. All else equal, a net productivity measure will always produce a higher productivity growth rate than the corresponding gross productivity measure. This is because the net measure has a smaller denominator which produces a higher rate of change.

Turning to the input price growth difference between the electricity distribution industry and the economy, EDB input prices grew at a trend annual rate of 3.14 per cent over the last decade while economy–wide input prices grew by 2.87 per cent. This led to an input price differential of 0.27 per cent.

Subtracting the input price differential from the productivity differential, we obtain a productivity–based regulation X factor –1.5 per cent.

APPENDIX A: THE DATABASE USED

Table A1: **Electricity distribution industry database, 1996–2014**

Year	Distribution Revenue	Energy	System Capacity	Customer Nos	Maximum Demand	Ratcheted Max Demand
	$m	GWh	GVA*kms (000s)	No (000s)	MW	MW
1996	697	22,088	1,567	1,499	4,072	4,072
1997	782	22,778	1,558	1,499	4,190	4,224
1998	822	23,206	1,607	1,500	4,218	4,283
1999	697	22,911	1,617	1,526	4,214	4,328
2000	837	23,796	1,611	1,551	4,344	4,455
2001	885	24,903	1,693	1,581	4,610	4,670
2002	927	24,858	1,785	1,610	4,728	4,777
2003	923	25,761	1,804	1,653	4,767	4,825
2004	920	26,499	1,833	1,677	4,806	4,874
2005	981	27,634	1,915	1,697	5,057	5,089
2006	1,022	28,154	1,985	1,724	5,078	5,153
2007	1,092	28,722	2,038	1,745	5,381	5,398
2008	1,173	28,775	2,091	1,764	5,501	5,529
2009	1,242	27,904	2,190	1,790	5,497	5,568
2010	1,322	29,277	2,262	1,805	5,704	5,761
2011	1,363	29,271	2,282	1,816	5,637	5,803
2012	1,421	29,280	2,329	1,827	6,005	6,105
2013	1,510	29,520	2,327	1,842	5,615	6,112
2014	1,499	29,098	2,378	1,862	5,798	6,163

Table A1: **Electricity distribution industry database, 1996–2014 (cont'd)**

Year	Circuit Length	Opex	Opex Price	Overhead Lines	Underground Cables	Transformers
	kms	$m	Index	GVAkms	GVAkms	MVA
1996	119,859	286	1.000	423	50	13,078
1997	121,101	303	1.014	426	51	12,866
1998	122,655	283	1.029	433	54	13,100
1999	124,253	272	1.042	436	56	13,015
2000	124,438	237	1.061	431	59	12,946
2001	129,490	241	1.107	438	59	13,072
2002	132,204	240	1.141	441	61	13,502
2003	131,200	254	1.152	445	62	13,751
2004	130,196	277	1.165	449	63	14,077
2005	132,642	307	1.195	449	65	14,438
2006	134,145	317	1.243	451	68	14,797
2007	134,827	341	1.292	453	70	15,115
2008	135,551	373	1.336	443	72	15,424
2009	138,236	386	1.418	446	75	15,845
2010	139,683	406	1.422	446	77	16,193
2011	138,862	420	1.458	451	79	16,431
2012	139,809	448	1.498	451	79	16,660
2013	137,526	439	1.518	460	79	16,920
2014	138,625	475	1.547	471	82	17,154

Year	AUC Overhead	AUC Underground	AUC Transformers & Other
	$m	$m	$m
1996	111	125	133
1997	113	128	136
1998	118	133	141
1999	121	137	145
2000	121	137	145
2001	123	139	148
2002	129	146	154
2003	133	150	159
2004	139	157	166
2005	143	163	172
2006	152	172	182
2007	162	183	194
2008	172	195	207
2009	184	209	221
2010	195	221	234
2011	206	233	247
2012	217	246	260
2013	226	257	272
2014	235	266	282

Table A2: **Non–exempt electricity distribution database, 1996–2014**

Year	Distribution Revenue	Energy	System Capacity	Customer Nos	Maximum Demand	Ratcheted Max Demand
	$m	GWh	GVA*kms (000s)	No (000s)	MW	MW
1996	563	18,046	905	1,196	3,264	3,264
1997	635	18,504	898	1,196	3,383	3,407
1998	674	18,795	912	1,194	3,413	3,463
1999	550	18,489	914	1,219	3,413	3,504
2000	680	19,231	906	1,240	3,515	3,605
2001	718	20,188	956	1,264	3,769	3,816
2002	761	20,124	1,017	1,289	3,859	3,897
2003	762	20,756	1,019	1,326	3,888	3,931
2004	762	21,437	1,026	1,341	3,918	3,965
2005	815	22,401	1,076	1,355	4,143	4,165
2006	846	22,791	1,111	1,377	4,124	4,194
2007	907	23,195	1,144	1,391	4,386	4,400
2008	945	23,076	1,163	1,406	4,469	4,493
2009	988	22,142	1,223	1,425	4,475	4,518
2010	1,057	23,382	1,264	1,437	4,612	4,660
2011	1,080	23,350	1,262	1,446	4,544	4,684
2012	1,121	23,336	1,285	1,454	4,876	4,952
2013	1,176	23,493	1,274	1,465	4,524	4,957
2014	1,176	23,493	1,295	1,479	4,639	4,971

Table A2: **Non–exempt electricity distribution database, 1996–2014 (cont'd)**

Year	Circuit Length	Opex	Opex Price	Overhead Lines	Underground Cables	Transformers
	kms	$m	Index	GVAkms	GVAkms	MVA
1996	84,661	240	1.000	285	45	10,687
1997	85,646	258	1.014	287	46	10,482
1998	85,639	236	1.029	288	48	10,649
1999	86,801	214	1.042	290	50	10,525
2000	87,136	180	1.061	285	53	10,402
2001	91,287	189	1.107	289	52	10,473
2002	93,748	185	1.141	290	53	10,847
2003	92,647	195	1.152	293	54	11,002
2004	91,546	217	1.165	296	55	11,209
2005	93,680	244	1.195	296	56	11,483
2006	94,553	249	1.243	298	58	11,752
2007	95,218	263	1.292	299	59	12,016
2008	95,354	287	1.336	284	60	12,199
2009	98,028	291	1.418	290	63	12,475
2010	99,318	306	1.422	289	65	12,728
2011	98,180	316	1.458	293	65	12,852
2012	98,791	342	1.498	292	65	13,010
2013	96,711	336	1.518	297	64	13,178
2014	97,215	366	1.547	305	66	13,321

Year	AUC Overhead	AUC Underground	AUC Transformers & Other
	$m	$m	$m
1996	76	111	105
1997	79	115	109
1998	81	119	112
1999	81	119	112
2000	81	118	112
2001	83	121	115
2002	86	126	119
2003	90	131	124
2004	93	136	129
2005	97	141	134
2006	102	149	141
2007	108	158	150
2008	115	168	159
2009	122	179	170
2010	130	190	180
2011	136	199	189
2012	144	210	199
2013	150	219	207
2014	155	227	215

APPENDIX B: DERIVING OUTPUT COST SHARE WEIGHTS

This study uses a multi–output Leontief cost function to estimate output cost shares, using a similar procedure to that used in Lawrence (2003). This functional form essentially assumes that EDBs use inputs in fixed proportions for each output and is given by:

(B1) $$C(y^t, w^t, t) = \sum_{i=1}^{M} w_i^t \, [\sum_{j=1}^{N} (a_{ij})^2 \, y_j^t \, (1 + b_i t)]$$

where there are *M* inputs and *N* outputs, w_i is an input price, y_j is an output and *t* is a time trend representing technological change. The input/output coefficients a_{ij} are squared to ensure the non–negativity requirement is satisfied, ie increasing the quantity of any output cannot be achieved by reducing an input quantity. This requires the use of non–linear regression methods. To conserve degrees of freedom a common rate of technological change for each input across the three outputs was imposed but this can be either positive or negative.

The estimating equations were the *M* input demand equations:

(B2) $$x_i^t = \sum_{j=1}^{N} (a_{ij})^2 \, y_j^t \, (1 + b_i t)$$

where the *i*'s represent the *M* inputs, the *j*'s the *N* outputs and *t* is a time trend representing the 18 years, 1996 to 2013.

The input demand equations were estimated separately for each of the 24 EDBs using the non–linear regression facility in Shazam (Northwest Econometrics 2007) and data for the years 1996 to 2013. Given the absence of cross equation restrictions, each input demand equation is estimated separately. Autocorrelation is also corrected for.

We then derive the output cost shares for each output and each observation as follows:

(B3) $$h_j^t = \{\sum_{i=1}^{M} w_i^t \, [(a_{ij})^2 \, y_j^t \, (1 + b_i t)]\} / \{\sum_{i=1}^{M} w_i^t \, [\sum_{j=1}^{N} (a_{ij})^2 \, y_j^t \, (1 + b_i t)]\} .$$

We then form a weighted average of the estimated output cost shares for each observation to form an overall estimated output cost share where the weight for each observation, *b*, is given by:

(B4) $$s_b^t = C(b, y_b^t, w_b^t, t) / \sum_{b,t} C(b, y_b^t, w_b^t, t) .$$

APPENDIX C: THE FISHER INDEX

Mathematically, the Fisher ideal output quantity index is given by:

(C1) $Q_F^t = [(\sum_{i=1}^m P_i^B Y_i^t / \sum_{j=1}^m P_j^B Y_j^B)(\sum_{i=1}^m P_i^t Y_i^t / \sum_{j=1}^m P_j^t Y_j^B)]^{0.5}$

where:	Q_F^t	is the Fisher ideal output quantity index for observation *t*;
	P_i^B	is the price of the *i*th output for the base observation;
	Y_i^t	is the quantity of the *i*th output for observation *t*;
	P_i^t	is the price of the *i*th output for observation *t*; and
	Y_j^B	is the quantity of the *j*th output for the base observation.

In this case we have either three or four outputs depending on the output specification (so m = 3 or m = 4) and 18 years (so t = 1, …, 18).

Similarly, the Fisher ideal input quantity index is given by:

(C2) $I_F^t = [(\sum_{i=1}^n W_i^B X_i^t / \sum_{j=1}^n W_j^B X_j^B)(\sum_{i=1}^n W_i^t X_i^t / \sum_{j=1}^n W_j^t X_j^B)]^{0.5}$

where:	I_F^t	is the Fisher ideal input quantity index for observation *t*;
	W_i^B	is the price of the *i*th input for the base observation;
	X_i^t	is the quantity of the *i*th input for observation *t*;
	W_i^t	is the price of the *i*th input for observation *t*; and
	X_j^B	is the quantity of the *j*th input for the base observation.

In this case we have either four or two inputs depending on the input specification (so n = 4 or n = 2) and 18 years (so t = 1, …, 18).

The Fisher ideal TFP index is then given by:

(C3) $TFP_F^t = Q_F^t / I_F^t$.

The Fisher index can be used in either the unchained form denoted above or in the chained form used in this study where weights are more closely matched to pair–wise comparisons of observations. Denoting the Fisher output index between observations *i* and *j* by $Q_F^{i,j}$, the chained Fisher index between observations 1 and *t* is given by:

(C4) $Q_F^{1,t} = 1 \times Q_F^{1,2} \times Q_F^{2,3} \times .... \times Q_F^{t-1,t}$.

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