EDB Productivity Study

A report prepared for the Commerce Commission

24 June 2024

FINAL REPORT

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EXECUTIVE SUMMARY

CEPA was engaged by the Commission to provide an independent estimate of productivity changes for the EDB sector. The Commission requested this work in the context of their statutory obligation under Part 4 of the Commerce Act 1986. This requires the Commission to publish a summary and analysis of information disclosed by electricity distribution businesses (EDBs) for the purpose of understanding changes to EDBs' performance over time. In this report we produce estimates of changes in EDB productivity indices using two methods. Our estimates are for the period 2008 to 2023 with separate estimates of total factor productivity (TFP) and operating expenditure (Opex) partial productivity. Our results are further divided between the industry overall, exempt and non-exempt EDBs.

We find that our productivity index falls on average by about 1.4% per year between 2008 to 2023. This finding is robust to a range of models and specifications. Most of the fall in the productivity index occurs between 2008 and 2014 with the productivity index only falling slowly or staying broadly constant between 2014 and 2023.

We find the inclusion of reliability weighs down on the productivity index as customer minutes off supply increased over the period. The weight given to reliability in the models produces a wide range of possible productivity index outcomes but regardless of weight, incorporating reliability results in a more significant decline in the productivity index.

We have also estimated operating expenditure (opex) partial productivity indices. We find that as real opex has grown more quickly than total expenditure, the decline in the opex partial productivity index is greater than for total factor productivity.

The table below shows the estimated change per year in total factor productivity and opex partial productivity from 2008 to 2023 for both methods. This is the average estimate across all models except the model including reliability. Over the entire period measured productivity has fallen by approximately 20%.

Table 1: Results by method (not including reliability models), per annum.

	Entire period – TFP	Entire period – Opex partial
Index-based	-1.3%	-1.4%
Econometric	-1.4%	-1.8%

Source: CEPA analysis of Commerce Commission ID data.

Productivity is a key long-term driver of economic well-being in the economy as a whole. Understanding the drivers of productivity is a natural and important focus of policy attention, especially in electricity distribution where there are natural monopolies subject to regulation. However, as outlined in this report, there are difficulties in the measurement of productivity. Some are unique to this sector. For example, the valuation of some outputs, such as reliability, is not straightforward. While some issues are not unique to the sector: productivity in the overall economy may be mismeasured because of unmeasured outputs such as investment in intangible assets.[1] As with results on economy-wide productivity, the results of the work reported here on sector productivity are valuable, but need to be interpreted with care.

In preparing this report we have therefore sought to be as clear as possible about the potential difficulties and limitations with studies of this kind. We are confident in the judgments we have made, and are confident that other practitioners, using the same data set, would reach a similar conclusion. Studies of this kind assist to identify issues – such as in data collection – which could improve the next round of productivity estimates in the future. Finally, this study serves to highlight areas (such as worker health and safety, or traffic management) where further analysis

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[1] For example, see Brynjolffson E, Rock D & Syverson D (2019) *The productivity J-curve: how intangibles complement general purpose technologies.* MIT initiative on the digital economy research brief.

may be valuable to identify the underlying drivers of the productivity results reported here. However, despite the potential difficulties which are explored in this paper, our analysis indicates that is difficult to draw a conclusion other than that productivity in this sector has declined.

Key results

While the outputs we measure (such as number of connections, line length, etc.) have increased materially over the 15-year period 2008 to 2023, the real cost of providing those outputs has increased by even more. As a result, the productivity indices we measure have declined over the period.

Table 2: Changes in key variables – 2008 to 2023

Variable	Change between 2008 and 2023
Real Opex ($)	45% higher
Real flow of capital services ($)	40% higher
Transformers (MVA)	33% higher
Overhead line capacity (MVA-KMs)	11% higher
Underground cable capacity (MVA-KMs)	40% higher
Connections (Count)	16% higher
Circuit length (KMs)	8% higher
Energy delivered (GWh)	16% higher
Maximum demand (GW)	11% higher
Ratcheted maximum demand (GW)	18% higher
Reliability – Planned minutes off supply	4.3 times higher
Reliability – Unplanned minutes off supply	2.4 times higher
Reliability – planned and unplanned minutes off supply	2.7 times higher
Normalised reliability – planned and unplanned minutes off supply	1.3 times higher

Source: CEPA analysis of Commerce Commission ID data.

There are a variety of limitations and uncertainties when estimating productivity indices. We have attempted to mitigate some of these issues by considering a range of methods and sensitivities. We build on the productivity work that was undertaken for the Commission previously in 2014. In addition to index-based methods we consider econometric methods, in which a cost function with a specific functional form is estimated, and productivity changes represent the change in costs not explained by other factors. Within our econometric methods we consider two functional forms – Cobb-Douglas and Translog. We also consider a wider range of output specifications including attempting to incorporate reliability into our models.

The table below provides a summary of the key results from the index-based methods. We use 9 different models each containing a different combination of outputs. The table below takes the average across 8 of these models dropping the reliability model. As discussed in the report, placing a value on reliability is difficult. However, given the trend in reliability we can conclude that productivity estimates would be lower if we were to incorporate reliability.

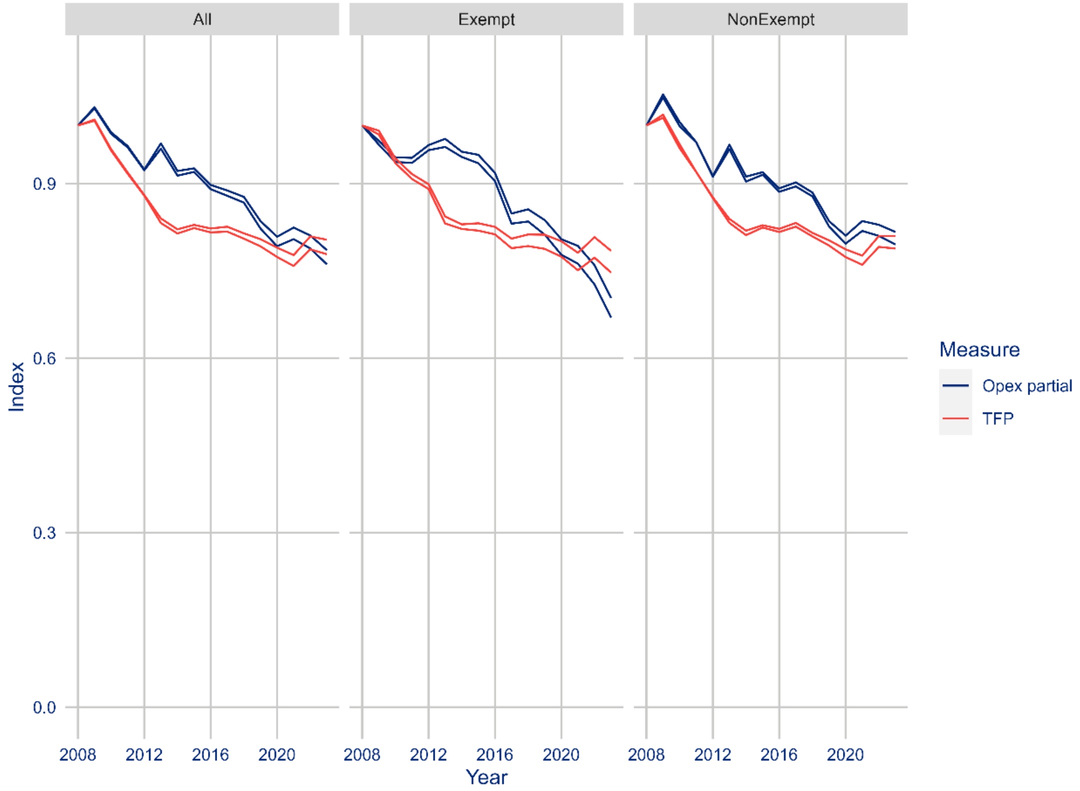
Table 3: Summary of key results – Index-based methods, per annum.

EDB type	Total factor productivity			Opex partial productivity		
	Entire period	Pre-2014	Post-2014	Entire period	Pre-2014	Post-2014
Non-exempt	-1.2%	-2.9%	-0.4%	-1.2%	-1.1%	-1.6%
Exempt	-1.4%	-2.5%	-0.7%	-2.1%	-0.2%	-3.7%
Overall	-1.3%	-2.8%	-0.5%	-1.4%	-0.9%	-2.1%

Source: CEPA analysis of Commerce Commission ID data.

Looking in more detail, we find evidence that the changes in the total factor productivity (TFP) indices can be divided into two periods. The TFP indices decline more rapidly over the first part of the period 2008-2014 and then roughly stabilise (or fall more slowly) over the second part of the period 2015-2023. This can be seen in Figure 1, which presents the change in the productivity index for the first of our models, using the minimum and maximum output valuations for each of the three sets of EDBs (All EDBs, Exempt EDBs, and Non-Exempt EDBs). The results for the remaining 8 models are similar. The opex partial productivity indices, in contrast, decline across the entire period. The growth in annualised capital costs is higher in the first part of the period and lower in the second part of the period.

Figure 1: Model 1 - Productivity indices (Output: Circuit length/ICPs)



Source: CEPA analysis of Commerce Commission ID data.

We also estimated productivity change as the change in the estimated cost function over the period. We refer to these estimates as 'econometric' methods. These models assume productivity is a change in costs that cannot be attributed to either the outputs included in the model or changes in input prices. As noted above, we estimated the cost function using both the "Cobb-Douglas" and "Translog" functional forms. The average results across of eight model specifications (not including reliability) and three EDB groups are set out below in Table 4 below. As can be seen, the results are broadly consistent with the "Index-based" approach set out above.

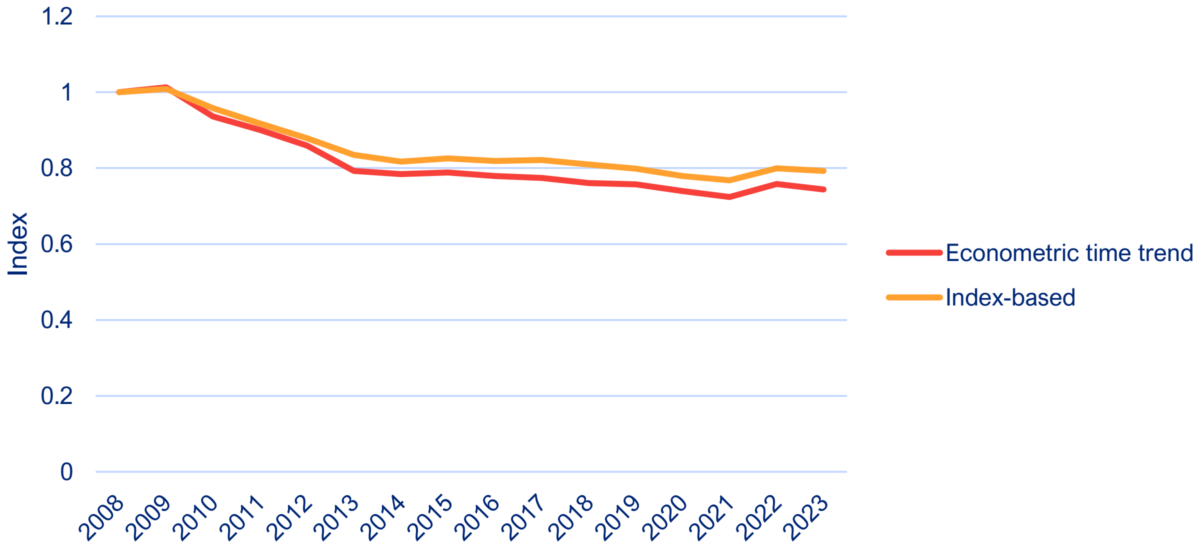
Table 4: Summary of key results – Econometric methods, per annum.

Type	Entire period - TFP	Entire period - Opex
Non-exempt	-1.6%	-1.6%
Exempt	-1.1%	-2.1%
Overall	-1.4%	-1.8%

Source: CEPA analysis of Commerce Commission ID data.

We can also estimate the change in the productivity index year-on-year with a small change in the econometric analysis. Figure 2 compares the two approaches for one of our models (circuit length and connections). Again, we see that there appears to be a more rapid decline in the index in the first part of the period, followed by a period of relative stability. We also find that both index-based and econometric methods provide a similar trend over time.

Figure 2: Comparison of the index-based and econometric approaches – Circuit length and connections



Source: CEPA analysis of Commerce Commission ID data.

At its simplest, productivity is the ratio of outputs to inputs. As a measure of inputs we have used a measure of annualised cost, equal to the sum of operating costs and capital costs. For capital costs we have used the sum of return on and of capital. The return on capital component is estimated using a single, average cost of capital for the period. This reflects the fact that the capital stock can only change slowly in response to changes in the relative price of capital and labour.

We note that interest rates declined substantially over this period. If we, instead, used a measure of capital cost based on an *annual* cost of capital, we would find that capital costs, and total costs have increased much more slowly over this period, suggesting a much lower decline in productivity. However, our view is that, as a productivity measure, this is potentially misleading, and could be quickly reversed if interest rates increase again (as they have done). As our objective is to obtain an estimate of the long-term change in overall productivity, we prefer a long-term static measure of the cost of capital, but acknowledge that this assumption may need to be revisited as the time series over which the analysis is carried out is lengthened in the future.

Conclusions

Using the data published by the Commission and using a variety of different methodologies for estimating productivity change, we find that the productivity measures we have estimated have declined across the period, for both Exempt and Non-Exempt EDBs. Although EDBs have expanded their outputs over this period, their expenditure has increased at a faster rate. Our analysis also indicates that incorporating proposed unmeasured outputs is unlikely to be sufficient to explain the substantial reduction in measured productivity.

1. INTRODUCTION

CEPA was engaged by the Commerce Commission to provide independent estimates of productivity changes in the EDB sector. This report sets out our findings taking account of submissions from stakeholders on our draft report.

1.1. THE COMMERCE COMMISSION REQUIREMENT

The Commission regulates New Zealand’s electricity distribution businesses (EDBs) under Part 4 of the Commerce Act 1986. The Commission has a statutory obligation under Part 4 to publish a summary and analysis of disclosed information for the purpose of understanding changes to EDBs’ performance over time. This analysis can examine the relative performance of EDBs including their productivity and efficiency. It is in accordance with this obligation that the Commission has commissioned us to undertake the work described in this report.

We understand that the Commission intends to undertake further work and this report contributes to phase one of their overall study. The primary focus of phase one is an assessment of the total factor productivity and partial factor productivity of EDBs overall. Phases two and three will instead focus on the comparative efficiency between EDBs.

The Commission regulates EDBs in two ways. They impose an information disclosure regime which applies to all EDBs. Under this regime EDBs are required to disclose certain information. These information disclosures provide the data we use in this report. The second way in which the Commission regulates EDBs is through price-quality regulation. This only applies to a subset of EDBs and sets out minimum standards of quality of service and limits on revenue that can be recovered from consumers of these services. These EDBs are referred to as non-exempt EDBs while those EDBs which are exempt from price-quality regulation are referred to as exempt EDBs.

This report responds to two specific Commission requests to provide:

- An estimate of the long-run productivity growth rate for the EDB sector overall and a separate estimate for non-exempt EDBs and exempt EDBs.
- Estimates of the operating expenditure and capital expenditure partial productivity over time.

This report was prepared at the same time as the Commission was considering DPP4. In response to our draft report several stakeholders pointed to the relevance of our findings on productivity for DPP4 in particular the setting of opex allowances. We have not been asked to comment on the DPP4 process as part of this work.

1.2. KEY ISSUES

The measurement of productivity of network businesses is difficult. We can demonstrate these difficulties by splitting productivity measurement into three categories – inputs, outputs, and method. Firstly, it is necessary to define inputs and it rapidly becomes apparent that network businesses depend on sunk capital for which cost is difficult to assign over time. Indeed, no correct method exists. Secondly, we need to define outputs which should align with our understanding of the services EDBs provide. This is constrained by the available data which forces a definition of these services that is stylised and reductive. Thirdly, we must choose our method to estimate productivity from the large menu of available methods which come with their own assumptions and limitations.

We have made a series of decisions in each of these categories. We have chosen our inputs and how to assign sunk capital costs over time. We have defined EDB services in a particular way which is both stylised and reductive. Finally, we have selected two methods for estimating productivity. We justify our choice of methods on the grounds that these methods have been widely used in New Zealand and Australia previously, focus specifically on the EDB sector using data from the information disclosures and will hopefully be accessible to a wide audience. The way we define inputs and outputs and the methods we have chosen are not the only way in which to undertake a productivity study.

The decisions we have made are not the same as the decisions made the last time the Commission considered productivity in 2014.[2] There are similarities and in many ways this report is an evolution and update of what was done previously. However, there are some crucial methodological differences which make a direct read across difficult. Throughout there are likely to be minor differences in implementation but two significant differences in overall methodology standout. The first is the way in which we produce output weights where we have abandoned the previous method and propose something which we consider to be more transparent and simpler. The second is the way in which we define capital inputs, where again we are proposing a simpler approach.

1.3. CHANGES FROM DRAFT REPORT

In this Final Report in response to stakeholder and Commission feedback, we have made some changes to the analysis presented in the draft report of 26th March 2024, none of which changes our overall findings. Differences between the results shown in the draft report and those presented here can be attributed to one of the following changes:

- For the average percentage growth rate in productivity, we now report geometric averages instead of arithmetic averages. This change has a minor impact on reported productivity.
- We corrected an issue with the treatment Vector’s assets in 2020. Our previous treatment led to Vector's assets (which are used to calculate flow of capital services) being stated approximately $290 million too high in 2020. This change has a minor impact on reported productivity. We describe this amendment in more detail in Section 3.1.1 under other data issues.
- We corrected an issue with how we treated the de-merger of Vector and Wellington in 2009. This impacted our measure of ratcheted maximum demand for Vector and by extension the industry overall. This change has a material impact on productivity models that included ratcheted maximum demand. However, this change has a minor impact on the overall results. We describe this amendment in more detail in Section 3.1.1 under other data issues.
- We have updated the assumed cost of capital for calculating our flow of capital services. This was previously set to 6.05% and is now set to an approximate estimate of the average over the period of 5.6%. This was estimated using a simplified methodology of a spread on top of the New Zealand ten-year bond yield. This change has a minor impact on the overall results.

The required changes to the code are noted in the change log provided alongside this report.

The Commission and stakeholders in their feedback also pointed to other avenues of analysis which we have now explored. These include:

- Considering how using normalised reliability numbers rather than raw minutes lost changes impacts our findings.
- Using a value for customer reliability based on New Zealand rather than Australian estimates.
- Considering a time-varying cost of capital.
- Considering other productivity measures such as those produced by Stats NZ.
- Considering the relevance of a range of other outputs.

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[2] Economic Insights (2014), Electricity Distribution Industry Productivity Analysis: 1996-2014.

1.4. THIS REPORT

The remainder of this report is structured as follows:

- **Section 2**: We set out principles for measuring productivity and some potential issues which need to be overcome.
- **Section 3**: We set out our methodology for measuring productivity and outline the assumptions we have made. We propose two broad methods for examining productivity changes which we label ‘index-based’ and ‘econometric’.
- **Section 4**: We provide the productivity results from our index-based methods. We also provide the results of the intermediate steps that go into creating a productivity index namely the construction of an input index and output index.
- **Section 5**: We provide the productivity results from our econometric methods. We estimate two econometric specifications, namely Cobb-Douglas and Translog. These two cost-function specifications are commonly found in other productivity studies.
- **Section 6**: We provide a discussion of our results bringing together the findings of both our methods. We also put these findings into context and consider alternate explanations for the changes in productivity that we observe. This includes considering potential missing outputs.
- **Appendix A**: Provides a brief description of the data.
- **Appendix B**: Provides the names of the reference files which provide the full outputs for the econometric models.
- **Appendix C**: Provides a brief technical description of the econometric approach.
- **Appendix D**: Provides figures showing the output trends under the various output models.
- **Appendix E**: Provides a description of previous productivity studies of electricity distribution networks.
- **Appendix F**: Provides the references.

2. MEASURING PRODUCTIVITY – PRINCIPLES

Productivity measurement can appear arcane. The modelling choices can appear unjustified. Methods and models can be used in such a way as to hide the real drivers while appearing to provide robust results. This section seeks to demystify the process of productivity measurement and to highlight the key issues and concerns that we have had to address. The objective is to give the reader a sense of the significance and/or the caveats of the results.

2.1. WHAT IS PRODUCTIVITY?

What, exactly, is productivity? Loosely speaking, productivity is a measure of how good certain firms (or whole economies) are at converting their inputs (resources) into outputs. We might be interested in looking at either how productivity varies across firms, or over time.[3] In this study we are primarily interested in how productivity in a sector varies over time.

2.1.1. Constructing an output index

Outputs are, of course, not an end in themselves – rather they are a means of delivering economic welfare or what economists describe as “utility”. Ultimately, therefore, we would like a measure of how good certain firms are at converting resources (inputs) into economic welfare or utility. To do this, we would need some measure of how much welfare or utility customers receive from a given set of outputs. Economists refer to this as a “utility function”.

Unfortunately, utility or welfare functions are not usually directly observable. However, basic production and consumption theory asserts that utility-maximising consumers will choose a consumption bundle where utility is maximised given the constraints of a finite income. At this point the ratio of the marginal utility of any two services is equal to the ratio of the prices faced by the consumer. It follows therefore that, at least for small changes in volumes, the change in utility is reflected in the sum of the output price times the change in volume for each output good or service.

In practice, in the assessment of productivity, it is common to construct an index of the output of a firm where the weight on each output is proportional to the price for that output. In other words, the index for the output of the firm is assumed to be proportional to:[4]

$$O_t = \sum_i P_{it} Y_{it}$$

Here Y_{it} is the measured volume of the *i*th output at time *t* and P_i is the price of the *i*th output at time *t*.

This approach works well enough in competitive sectors where the prices are easily observed. It doesn’t work as well when assessing the productivity of, say, public sector service providers (such as roads or libraries) where prices don’t exist (perhaps because the service is provided for free), or where the prices are regulated well below the marginal value of the service to customers. There can also be problems applying this approach where the quality of the output varies, or where some of the outputs of the firm are actively harmful (e.g., harm to the environment, or injuries to workers, or the public). As we will see, there are also problems applying this approach to EDBs where the output of EDBs cannot easily be summarised in a few variables.

There is another issue with constructing an output index using price-based weights: The prices themselves may change over time. This raises the question of whether a given change in output should be valued using (a) the

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[3] Productivity is defined by the New Zealand Productivity Commission as a measure of the volume of outputs produced for a given set of inputs. The Australian Productivity Commission notes that productivity is measured as the ratio of the quantity of output produced to some measure of the quantity of inputs used.

[4] As noted in footnote 6, this form of the output index can be justified under the assumption that the utility/welfare function is homothetic.

original prices; or (b) the final prices; or (c) some combination of both. Similar problems arise when comparing the productivity of firms that face different prices. We discuss these issues further below.

2.1.2. Constructing an input index

As we have seen, the productivity of a firm is a measure of how effective it is at converting its inputs into economic welfare or utility. Therefore, we also need a way of valuing the cost of the inputs used by a firm – that is, we need a function which yields the total cost of a given set of inputs.

This process is straightforward when we have good measures of the prices of the resources used by the firm. In this case, we can construct an index based on the sum of the price of each input multiplied by the volume of each input used. This is also known as the 'cost' incurred by the firm. In other words, the index for the input of the firm is proportional to:

$$I_t = \sum_i W_{it} X_{it}$$

Here X_{it} is the measured volume of the *i*th input at time *t* and W_{it} is the price of the *i*th input at time *t*. This expression is also equal to the cost of the firm at time *t*.

This approach is commonly used in practice. But some of the same issues above recur in this context. For example, where there are different qualities of a given input (such as labour input) we must be able to identify the relevant prices for each level of quality. Another key problem arises when the provision of the services of the firm requires sunk long-lived investments. In this case, it is not possible to estimate the "amount" of the input that is consumed in any given short period. This issue is discussed further below.

In addition, as noted above, the prices for inputs may change over time. As before, this gives rise to a question in productivity measurement as to whether to value a change in inputs using the original prices, or the final prices, or both, or some combination.

2.1.3. Partial compared to total factor productivity

It is also possible to split out the various inputs in the input-index to focus on each one at a time. When a productivity index is constructed using a subset of inputs this is referred to as a partial factor productivity index. For this report we construct an operational expenditure partial factor productivity index. The reason for this is the Commission's base-step-trend process for setting operational expenditure allowances is informed by an estimate of the productivity factor.

Other issues arise when the focus is narrowed to partial inputs. Inputs are likely to have some degree of substitutability. This means that focusing on a subset of inputs may lead to a misleading picture of productivity changes. There may have been substantial growth in one input, but this is balanced out by reductions elsewhere. This is missed when the focus is on partial inputs. It is also the case that when the analysis is extended to relative comparisons of EDBs or groups of EDBs using a partial measure may fail to take account of how much of the other input is available. An EDB that has access to a large modern capital base at the beginning may need to spend less on operational expenditure than an EDB that has a smaller older capital base. This difference is usually not accounted for under a partial factor productivity measure.

2.2. APPROACHES TO MEASUREMENT OF PRODUCTIVITY

We will use two approaches to estimate productivity. The first we refer to as 'index-based' while the second as 'econometric'. There are a range of other approaches that could be used to consider productivity growth or the potential for productivity growth in the EDB sector. For example, considering data from other sectors. These methods have their own advantages and disadvantages. The two methods we have chosen have the advantage of specifically focusing on the EDB sector itself using data from the information disclosures. There are of course several challenges to narrowly focusing on the EDB sector which we cover in section 2.3.

2.2.1. The Index-Based Approach

The first approach forms the productivity index as the ratio of an index of outputs to an index of inputs.[5] Specifically, under this approach the productivity index is estimated as the ratio of the output index to the input index, normalised to be equal to one in the base year (year 0, say):[6]

$$\frac{O_t}{I_t}$$

Where this ratio is larger than 1, this is interpreted as an increase in productivity relative to the base year (that is, that the firm or the sector is producing more economic welfare per dollar of resources used). We will refer to this as an **index-based** approach.

The output and input indices are usually normalised to be equal to one in the base year. When the prices are changing (as well as the quantities) that normalisation can be carried out in two different ways. In some cases, this choice can make the difference between assessing that value of output (or the cost of input) has increased or not.

Under the **Laspeyres index** approach, the *original prices* are used to normalise the index. In this case the index is computed as:

$$O_t = \frac{\sum_i P_{i0} Y_{it}}{\sum_i P_{i0} Y_{i0}}$$

Under the **Paasche index** approach, the *new prices* are used to normalise the index. In this case the index is computed as:

$$O_t = \frac{\sum_i P_{it} Y_{it}}{\sum_i P_{it} Y_{i0}}$$

In the approach we use below, we will be using fixed prices for valuing output, so there is no difference in the Laspeyres and Paasche index and we can set this issue aside. This implicitly assumes that the relative value customers place on outputs does not change over time. This is not necessarily the case, and we mitigate this problem with sensitivity analysis around the prices. However, our approach for the input index implicitly assumes time-varying prices and we propose to apply the Fisher index. The “Fisher” index is the geometric mean of the Laspeyres and Paasche indices.

2.2.2. The econometric approach

It can be difficult to measure or value the output of firms in some contexts. A second-best alternative is to simply assume that the firm is producing the efficient combination of outputs and to focus attention on the cost side.

Specifically, under this approach we seek to estimate a cost function. A cost function is a mapping from a given vector of outputs to an average cost of providing those outputs. For a given set of outputs Y_{it}, the cost function is:

$$C_t(Y_{1t}, Y_{2t}, \dots, Y_{Nt})$$

An improvement in this value *for a fixed vector of outputs* is then interpreted as an improvement in productivity. This approach can reflect improvement in technology or practices which reduce costs, but neglects changes in outputs that may also contribute to improving the welfare of customers.

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[5] See McLellan, Nathan (2004): Measuring Productivity using the Index Number Approach: An Introduction, New Zealand Treasury Working Paper, No. 04/05, New Zealand Government, The Treasury, Wellington and Lawrence, Denis and John Kain (Economic Insights) (2014), Electricity Distribution Industry Productivity Analysis: 1996–2014 Report prepared for Commerce Commission, 30 October 2014.

[6] This formula is exact in the special case when preferences are “homothetic” (which means that the utility or welfare function is homogeneous of degree 1). Suppose we have a utility or welfare function $f(Y)$. We can expand this using the Taylor series approximation relative to the base year: $f(Y) \approx f(Y_0) + \nabla f(Y_0) \cdot (Y - Y_0) = \nabla f(Y_0) \cdot Y = P \cdot Y$, when we choose prices $P = \nabla f(Y_0)$. It follows that the output index above $O = P \cdot Y$ is a good measure of utility/welfare in this case.

Since this approach requires the estimation of a cost function, we will refer to this as an **econometric** approach.

There are pros and cons of both approaches. The econometric approach has the advantage of not requiring estimation of the weights ("prices") on the outputs. On the other hand, by focusing on the cost side, the econometric approach cannot pick up improvements in productivity arising from, say, a better matching of the outputs to the preferences of customers. Given the pros and cons we consider both approaches.

2.3. APPLICATION TO EDBS: WHY MEASURING PRODUCTIVITY OF EDBS IS HARD

Let's now think about applying these ideas to Electricity Distribution Businesses (EDBs). We immediately find that there are several problems which complicate this task.

2.3.1. EDBs produce a large number of different services which cannot easily be aggregated into a few variables

Assessing the productivity changes of a firm is more straightforward when the firm produces one or two homogeneous products. In this case, the total output can be simply counted, and a comparison made with the inputs required.

Unfortunately, EDBs do not provide a small number of homogeneous services. Instead, EDBs provide the service of transportation of a given volume of electricity from a point of connection with the transmission grid to individual homes and businesses at different geographic locations. *Each connection to each customer in a different geographic location is, in principle, a different service*. An EDB with thousands of customers provides thousands of distinct services. This one-sided description of the service, from transmission to customer, is also changing with the growing importance of distributed energy resources feeding energy into the distribution network.

Fully describing the service provided by EDBs would therefore require information on the geographic location, the load profile, and the correlation of the load profiles of each and every customer. We would also need information on the points of connection to the transmission network and the physical constraints imposed by the terrain (i.e., valleys, rivers, lakes, etc.). This information is not normally available.

In order to make progress, the conventional approach is to assume (a) that each EDBs has constructed an efficient network to serve the customers they face; and (b) that an efficient network can be summarised in a small number of variables – such as the total line length and the number of connections. With these assumptions these variables can be thought of as "intermediate" or "proxy" outputs which summarise the key features of the outputs than customers actually value.

Neither of these assumptions will necessarily hold in practice. For a given set of customers, the efficient network to serve those customers will depend on factors such as the degree of correlation of their demand – which cannot be summarised in a few aggregate variables. The networks created by an EDB will not always be optimal or efficient. Even if two EDBs provide services to identical customers in identical geographic locations, if one EDB has inefficiently over-invested in, say, line length, under the assumptions above, this EDB will incorrectly appear to be providing more output. In other words, this approach does not allow us to assess whether an EDB has an inefficiently-configured network.

Nevertheless, these assumptions are necessary to make progress. This approach is common in productivity measurement for EDBs.[7,8] It is also the approach adopted in the previous productivity study undertaken for the Commission in 2014. In effect, we are replacing the actual outputs of EDBs (that is, the provision of a reliable supply of electricity to different types of customers and different geographic locations) with *proxies* describing the key

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[7] Edvardson and Førsund (2003) observe: "Due to the high number of customers for a standard utility it is impossible to implement the conceptualization of a multi-output production function to the full extent. The usual approximation is to operate with total energy delivered and number of customers separately as outputs".

[8] We provide some examples of outputs used in other productivity studies of network businesses in Appendix E.

drivers of the efficient network necessary to serve those customers (such as line length and number of connections).

This observation is important as, in the productivity assessment of EDBs it is common to use as measures of *output* variables which would normally be considered an *input* (such as line length). This can appear at first confusing – and has contributed to a degree of confusion in the EDB productivity measurement literature.[9] We merely observe that this approach can make some sense when we keep in mind that the chosen outputs (such as line length and number of connections) are *proxies* for describing the efficient network which provides the actual outputs that customers value – i.e., the delivery of electricity to customers in different geographic locations.

However, there is a further problem. As noted earlier, in principle, we should weight the measures of output in the output index by the value of the corresponding output to customers. But how much do customers 'value' these proxies for the outputs of the EDB; what weight should we place on each proxy output in the output index? For example, how much do customers value 'line length'? Superficially, at least, we might think that customers do not value 'line length' at all since they do not care how much line it takes to provide service to their location; they care only about the service they receive.

To get around these problems we have followed historic practice and identified cost-based prices to produce output weights. Specifically, we have sought to answer the question: how much extra *cost* is incurred for providing an additional unit of each output. This additional cost is interpreted as the price (or the 'value') of the output in question. It is important to keep in mind that – especially in a regulated setting – these cost-based prices may be much lower than the amount that customers are willing to pay for a service.[10] Put another way, the additional consumer surplus created by connecting an additional customer to the distribution network may be much larger than the additional cost incurred by the EDB in providing that service.

By itself, this observation is not necessarily a problem as, in the construction of the index only the relative - rather than absolute – prices matter. But the use of cost-based prices may also distort relative prices. For example, underground cables cost more to install than overhead lines and this is reflected in a higher relative price for underground lines. As such, the implicit assumption in the model is underground cables are more valuable to the customer. We mitigate the risk of having incorrect relative prices by undertaking sensitivity analysis.

2.3.2. The handling of long-lived sunk investments is inherently problematic

When measuring the outputs and inputs of a firm we have implicitly assumed that those outputs and inputs can be counted *in a given time period*. Problems arise, however, when some of the outputs or inputs are inherently long-lived – longer than the period over which we are measuring productivity. In this case there is no clear way to allocate the costs or benefits of those long-lived assets to the period in question.

This problem arises when the inputs required by the firm must be customised or bespoke, and so cannot be purchased on a competitive market. In this case there is no 'rental' market for the assets involved.

This is particularly a problem for EDBs. EDBs tend to be capital intensive. A large proportion of the costs of an EDB are the costs associated with sunk long-lived investments that are customised to the operation of the firm (in poles, wires, transformers, switches, and so on).

If we are to assess the productivity of a firm (that is, the ratio of outputs to inputs) in a specific period we need some allocation of the costs of these long-lived investments to the period in question. There is no unique, or unambiguous

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[9] This is reflected in the fact that there is no consensus in the literature on what should be an input and what should be an output. Jamasb and Pollitt (2001) write: "[Table 2] shows that [benchmarking studies of electricity distribution utilities] use a wide range of input and output variables. This observation is somewhat contrary to the general belief that the underlying design and technologies of transmission and distribution utilities are rather similar. The variety of the variables that have been used shows that there is no firm consensus on how the basic functions of the utilities are to be modelled. For example, in some cases a variable is used as an input and in others the same variable is used as output."

[10] The amount that customers are willing to pay for an output is related to the change in their welfare or surplus when they consume the output, not the change in the cost of producing the output.

way to carry out this allocation. Different choices of the allocation methodology will have a large impact on the apparent relative productivity.

There is no simple answer to this question. Many productivity studies simply abandon attempts to include capital expenditure in the productivity assessment, focusing instead on assessing operating expenditure. This introduces its own problems as it is affected by capex-opex substitution decisions by the EDBs.

We have selected a methodology for the allocation of capital cost in the sections that follow. However, it should be kept in mind that other methodologies could be chosen. The choice of allocation of capital costs depends on factors such as the preferred long-term path of prices, which depends, in turn, on long-term forecasts of costs and demand. Such forecasts are inherently uncertain and often controversial. The methodology we have chosen in effect assumes that we are in a steady state with capital costs allocated to smooth the revenue allowance over time.[11]

2.3.3. It is tricky to value the quality of EDB services

In principle, the value of the output supplied by a firm could vary with the quality of the services it provides. In principle, a change in the quality of the service of a firm should be reflected in a changed valuation in the output index. But how should we do this in the case of EDBs?

It is widely recognised that EDB customers care a great deal about the reliability of the service. Involuntary loss of supply is considered to have a material impact on the overall economic value of the network. It follows that quality of service measures should be included when comparing how the productivity of EDBs has evolved over time.

However, as usual, there are quite material problems to address. One of the problems is that reliability is, to a large extent, driven by weather conditions which are exogenous to the actions of the EDB. It may take several years of data before it is possible to distinguish the actions of the EDB (in improving resilience, say) from just the luck of the weather. With changing climatic conditions this task is even more complicated.

More importantly, even if we had a good measure of the reliability of the network that was under the control of the EDB, it is not clear how much to change the ‘value’ (in the output index) of each service in response to reliability changes.

As we have noted above, in principle a decline in reliability reduces the value of the service provided by EDBs and therefore should reduce the weighting of the output in the output index. But we observed above that the ‘values’ associated with each output in the output index is estimated using cost-based measures that do not reflect the true value of the service to customers.

In principle, it should be possible to estimate the impact of increased reliability on the cost of providing EDB service, with the expectation that more-reliable service should be associated with higher costs. However, in practice, this has proven difficult. This could be because, in the short-run, an increase in adverse weather events gives rise to both involuntary outages and increased cost to the EDB (in restoring service). It could be that building a more resilient network shows up in additional capital costs which, as noted above, are difficult to allocate to a single year. In any case, it has proven difficult to obtain a cost-based ‘value’ of reliability.

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[11] It might be thought that issues of the allocation of capital costs do not affect productivity indices *in the long run*. This does not appear to be the case. Let’s suppose we have two firms that are absolutely identical in all respects except their depreciation profile. Both firms start with an opening RAB of $1000, an asset life of ten years, and have no capex. Both firms depreciate the asset base to zero over the ten year life. However, the first firm depreciates faster in the first five years ($150/year) and slower in the second five years ($50/year), while the second firm reverses this profile. Let’s suppose we construct an annualised cost index equal to the opex (which is zero) plus return on and return of capital (WACC of, say, 8%). The annualised cost of the first firm starts high and declines over time, suggesting strong growth in productivity. The annualised cost of the second firm starts at a lower level and increases over time, suggesting a decline in productivity, despite the firms being equal in all respects. This effect can only be eliminated by looking at much longer time periods (ideally as long as the life of the underlying assets).

In section 4.2.1 we discuss how we have addressed this problem.

2.3.4. We do not have good information on all of the outputs of EDBs

Not all of the outputs of an EDB can be measured as services provided to their own customers. The activities of EDBs have an impact on the broader community and industry workforce – and often this impact is harmful. In principle, these harmful effects should be taken into account in productivity assessment. For example, EDBs may have an impact on:

a) The health and safety of workers or the broader public;
b) The broader environment, such as bushfires;
c) The aesthetic environment, such as through undergrounding.

As community standards change over time, governments may require higher standards for, say, worker safety, or bushfire risk, or undergrounding. In principle, these higher standards correspond to higher levels of "output" by the EDB. But, incorporating these higher outputs into productivity assessment requires information on, say, the incidence of worker injuries and deaths, or bushfire starts, which is not normally collected in productivity studies. In the absence of such information, it may appear as if industry productivity has declined when in fact the total value of the output produced by the industry has increased (due to, say, the value the community places on reduced worker deaths or reduced bushfire starts).

Even where aggregate data is available, such as in the case of undergrounding, the value attached to this output may vary widely across the community (e.g., between rural and urban areas). Two otherwise identical firms may have different undergrounding policies, in response to the differing preferences of their communities – complicating the comparison of their productivity.

2.3.5. The services provided by EDBs are changing

The final observation we can make is that the 'outputs' of an EDB are not static over time. The services we require of EDBs are changing.

With the increasing penetration of Distributed Energy Resources (DER), distribution-network customers are increasingly able to generate and store electricity, for later injection into the grid. Amongst other things, this means that EDBs are increasingly being required to handle two-way flows. Congestion can occur on the network in not just the import, but also the export direction. Increasingly EDBs are being forced to incur resources to upgrade their ability to monitor and control bi-directional flows on individual feeders. This process is likely to continue in the future as EDBs evolve into distribution system operators and distribution market operators.

In principle, these new outputs should be captured in the productivity assessment task. But it is not yet clear how we should do so.

2.4. INTERPRETING THE RESULTS OF PRODUCTIVITY ASSESSMENT

In the sections that follow we have carried out an assessment of the changes in productivity in the electricity distribution sector in New Zealand. However, it is important to keep in mind that the results of this assessment are likely affected by the modelling choices made, including:

- The choices of the outputs, noting the problems above in aggregating outputs in a few variables, and the problems of measuring outputs such as worker safety.
- The valuation of those outputs, including the problems of cost-based prices and the handling reliability noted above.
- The choices of inputs, including the problems of handling capital expenditure.

While we have exercised professional judgement and expertise, we recognise that the practical difficulties are such that it is not possible to make a definitive statement that we have fully and accurately captured changes in productivity in this sector. For this reason, we prefer to describe our results as changes in a *productivity index* rather than changes in *productivity*. This small distinction emphasises that the results depend on the modelling approaches chosen, as we describe in the sections below.

3. MEASURING PRODUCTIVITY – OUR APPROACH

3.1. KEY METHODOLOGICAL ISSUES: OPTIONS AND OUR APPROACH

We have decided to use two broad methodologies. There are two drivers of this decision. Firstly, these broad methods have been used in productivity studies for regulators in New Zealand and Australia before. We hope this means that these methods should be at least somewhat familiar to the intended audience of this report. Secondly, they focus specifically on the EDB sector using data from the information disclosures.

We have also tried to keep in the mind how these productivity estimates may be used in the regulatory process going forward. While our understanding is the Commission has commissioned this report primarily for performance reporting reasons the productivity estimates used here may be referred to in future revenue setting processes. For example, in the base-step-trend process for establishing operational expenditure allowances. As such we have attempted to align our treatment of inflation and our reporting of opex partial factor productivity with the way the Commission undertakes this procedure. In other parts of the framework productivity estimates act in a more indirect way. For example, they can set the tone of discussions for overall revenue allowances.

We describe the first method as ‘index-based’. This method can also be described as ‘non-parametric’ in that the method makes no explicit assumptions about the underlying process which drives costs. This can be contrasted with our second set of methods which we describe as ‘econometric’ falling under the category of ‘parametric’. In these methods, we are explicitly assuming that costs for EDBs are created following a particular functional form, in our case Cobb-Douglas or Translog. This is a stricter set of assumptions.

For both of our methods we need to determine the inputs and outputs and measure annualised capital costs. As such, sub-sections 3.4.1 and 3.4.4 below are relevant to both methodologies.

With an indexed-based method we need to explicitly decide how to weight multiple inputs and multiple outputs. As described in Section 3.4.3 below, we use the results from our econometric models to inform the output weighting process. This is another attempt at simplicity. We observe that other productivity studies have used a different cost model (for example Leontief[12]) to set output weights and then used Cobb-Douglas in an entirely separate process to estimate the productivity time trend. We use Cobb-Douglas for output weights and then use that same model for the separate estimation of the productivity time trend.

3.1.1. Determining inputs and outputs

As noted in section 2.1, the first stage in a productivity study is to determine the inputs and the outputs. In this section we discuss how we have determined inputs and outputs. We also provide some indication of the relative trends of these inputs and outputs over time.

Inputs

As noted in section 2.1.2, the input index should, in principle, include all of the inputs used to produce the outputs, weighted by the input price of each of those inputs. We therefore propose to use, as the input index, total annualised cost. This is not the same definition that was used in the previous productivity study as demonstrated in Box 1 below.

More specifically, we divide the inputs into two categories - the flow of capital services and operational expenditure (opex). Our opex index is shown below while the construction of the “flow of capital services” is described in Section 3.1.4.

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[12] A Leontief production function assumes that input factors must be used in “fixed proportions” and there is no potential for substitution between different input factors. There is also a Diewert (Generalised Leontief) production function and a corresponding Diewert (Generalised Leontief) cost function.

We adjust each of these categories of inputs for inflation, which means we are applying the real annualised dollar value of inputs in our analysis. The inflation index that we use for opex and flow of capital services is different. In both cases we apply the same approach the Commission used for inflation as for DPP3.[13] The inflation series for opex was determined by weighting 60% labour cost index (LCI) and 40% producer price index (PPI). The inflation series for capital services was determined using the capital goods price index (CGPI). All inputs into this procedure are as published by Stats NZ.

Box 1: Differences in the treatment of inputs between Economic Insights and this report

We have proposed that the input index be based on a measure of all costs incurred by the EDB. In effect, this means that each input is weighted by the price of that input. This is different to the approach used by Economic Insights in their previous work assessing productivity of New Zealand EDBs.

Our approach is the same as Economic Insights in the treatment of operating expenditure. As with Economic Insights, we have simply included operating inputs at their total cost in the input index. The difference with Economic Insights is in the treatment of the capital inputs.

The previous Economic Insights report accounted for capital inputs by focusing on three capital inputs: transformer capacity, overhead line capacity and underground cable capacity. Economic Insights have then chosen weights to apply to each of these inputs by choosing prices based on allocating a share of the total annualised capital costs. Depending on the choice of these prices/weights this approach can just yield back the total annualised capital costs, which is the approach we have chosen.

Our analysis suggests that the only difference between our approach and the Economic Insights approach is in the handling of these weights. Specifically, we understand that the only difference between our approach and the Economic Insights approach comes down to the difference between the Laspeyres vs Paasche Index. We consider this difference to be of limited economic significance. In our view, it is simpler and clearer to just include the total annualised capital costs in the input index. In any case, we compare the resulting input indices using our approach and the Economic Insights approach in Section 4 below.

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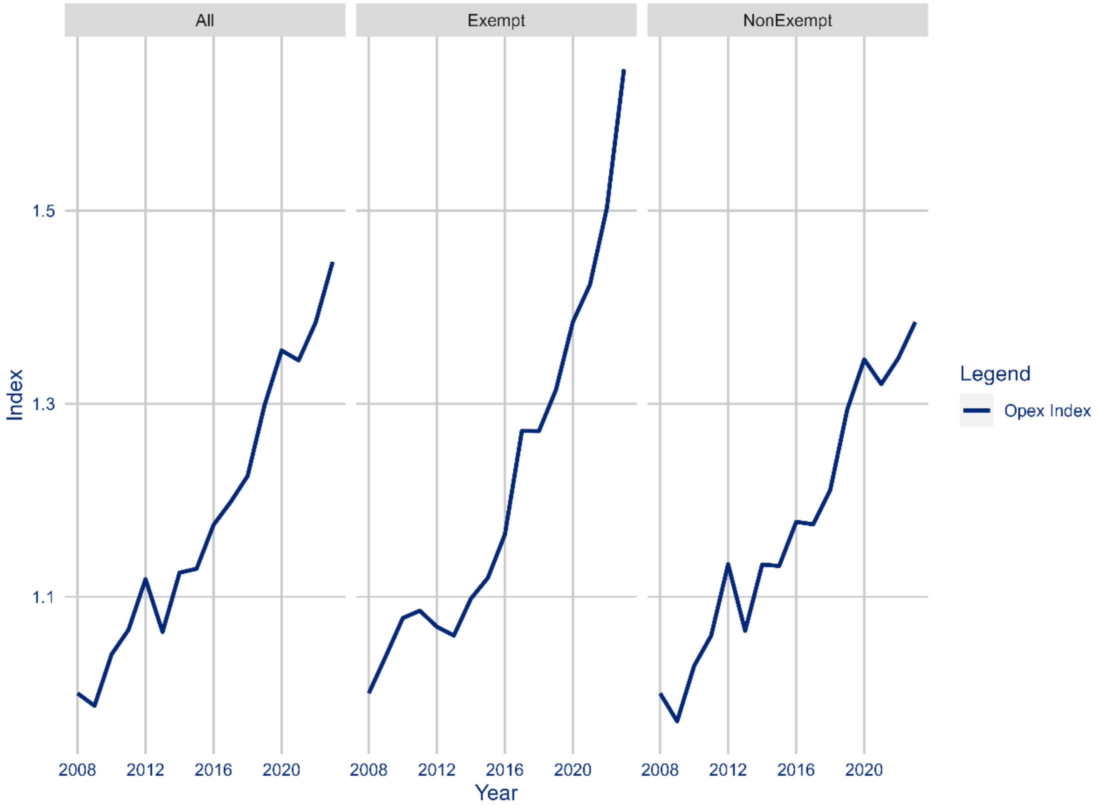
[13] We replicated the procedure for inflation as applied in the Commission’s spreadsheet Price-Quality Regulation 1 April 2020 DPP Reset – Input cost inflators model – Final determination.

Figure 3: Opex index



Source: CEPA analysis of Commerce Commission ID data.

Outputs

As discussed in section 2.1.1, 'outputs' are, in principle, anything produced by the firm that is valued by customers. Anything valued by customers is potentially an output, including quality, timeliness, aesthetics and so on. If customers are prepared to pay for something, even if they do not actually pay under current arrangements, then this is a valuable output.

In principle, outputs can include negative and harmful effects of the firm's activities, such as bushfires. These can be viewed as negative externalities that customers are willing to pay to avoid. In theory, these can be included in the analysis as negative outputs.

We discussed in section 2.3 that applying these seemingly simple principles to measuring EDB output is not straightforward. We have constrained our analysis to the data available in the EDB information disclosures. This is justified on practical grounds. The data contained in these disclosures does not cover the full range of potential outputs. There may be valuable activities that EDBs have either started doing or increased their delivery of since 2008 that are not included. This is a fundamental limitation of any productivity analysis.

The table below shows the outputs we have identified in the data as well as our two inputs. We contrast our classification of input or output with that used in the previous productivity analysis commissioned by the Commission in 2014. Furthermore, as highlighted in Appendix E, many of these outputs are the same as the outputs considered in other recent productivity studies of electricity networks.

As noted in section 2.3.1, we do not consider variables such as line length, or transformer capacity to be outputs that are directly valued by end-customers. However, these variables may be useful in summarising the key characteristics of the theoretically optimal network necessary to provide the services that *are* directly valued by end-customers. We are agnostic as to how best to describe that theoretical optimal network. Therefore, we do not take a firm line on which variables should be included. As will be seen in section 4, we have considered a range of different combinations of variables which are used as proxies for outputs.

The other obvious takeaway from the table below is that real annualised expenditure has increased faster than most outputs. This relationship is what is ultimately captured by the productivity index results we present in Section 4 and the econometric time trend results we present in Section 5. The use of these methods allows for a quantification of this relationship but the overall direction can be simply read from the table below.

Table 3.1 shows the change between 2008 and 2023 and for reliability this may provide a slightly misleading picture. This is because 2023 was a particularly eventful year with substantial weather-related reliability events for several EDBs. In the sub-section on reliability below Figure 4 demonstrates the trends in planned and unplanned minutes off supply over time.

Table 3.1: Classification of inputs and outputs

Data	Previous classification[14]	Our classification	Change between 2008 and 2023
Real Opex ($)	Input	Input	44% higher
Real flow of capital services	Not included	Input	39% higher
Transformers (MVA)	Input	Output	32% higher
Overhead line capacity (MVA-KMs)	Input	Output	11% higher
Underground cable capacity (MVA-KMs)	Input	Output	40% higher
Connections (Count)	Output	Output	15% higher
Circuit length (KMs)	Output	Output	8% higher
Energy delivered (GWh)	Output	Output	15% higher
Maximum demand (GW)	Output	Output	11% higher
Ratcheted maximum demand (GW)	Output	Output	23% higher
Reliability – Planned minutes off supply[15]	Not included	Negative output	4.3 times higher
Reliability – Unplanned minutes off supply	Not included	Negative output	2.4 times higher

Source: CEPA analysis of Commerce Commission ID data.

For many of the variables in the table above, which includes connections, circuit length, energy delivered and transformer capacity, we have undertaken very limited data transformation. Since, in the case of the index-based method, we are interested in sector-wide productivity we have simply summed the relevant variables (e.g., connections, line length, etc.) to form values for the distribution sector as a whole. In the case of the econometric methods (for which the analysis is at the EDB level), these variables are introduced into our models simply as they are shown in the information disclosures. There are three variables where we have applied some additional data transformations that are explained below – ratcheted maximum demand, overhead line and underground cable capacity and reliability.

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[14] As per the previous productivity study undertaken for the Commission in 2014.

[15] Both planned and unplanned minutes off supply is raw data and is not normalized.

Ratcheted maximum demand

Ratcheted maximum demand is a transformation of the maximum demand series. The ratcheted maximum demand in year *t* is the highest maximum demand achieved by an EDB over all previous years [2008,*t*]. We have calculated the ratcheted maximum demand for each EDB individually and then summed across EDBs to provide the figure in each year. This leads to a higher value than if we calculated maximum demand across EDBs and then apply the ratchet to the sum. This is because maximum demands between EDBs are not perfectly correlated.

Whether to use *ratcheted* maximum demand as opposed to maximum demand in a productivity study depends on one's view as to whether a temporary peak demand can be addressed through temporary expenditure (such as opex). If a temporary peak could be handled through temporary increase in opex (e.g., by renting a large mobile battery), there is a case for measuring productivity using maximum demand. On the other hand, if an increase in peak demand can only be handled through long-term capital expenditure, then it is perhaps more reasonable to measure productivity using ratcheted maximum demand.

In our productivity analysis we elect to use ratcheted maximum demand. This implicitly assumes that EDBs cannot clearly trade-off meeting maximum demand using other means such as opex. This results in higher measured productivity than if maximum demand were used. It is possible that the appropriate trade-off between using ratcheted maximum demand and maximum demand for productivity estimation has changed over time due the technology allowing more flexibility.

Overhead and underground line capacity

We want to include a measure of circuit capacity as an output. Megavolt-amperes (MVA) is a measure of apparent power in a circuit and is the product of current multiplied by voltage and can be used to represent circuit capacity. We can further multiply MVA by circuit length to get a measure of circuit capacity in MVA-km terms.

Circuit length was represented as an output in the previous productivity study while overhead/underground capacity was represented as an input.

Our preference is to treat both as outputs. This is not because we view circuit length as directly reflecting a customer-valued output of an EDB. Customers are likely agnostic regarding how much line an EDB needs to run to provide services. Instead, circuit length is a proxy for describing characteristics of the efficient network for providing the services that the customer does desire (i.e., reliable service at the customer's location as discussed in Section 2.3).

This argument that circuit length can be treated as output can be easily extended to overhead/underground line capacity. In much the same way as location of customer being outside EDB control it could be argued that their demand characteristics are also outside EDB control. In this way circuit length as output can be extended to circuit capacity as output. Furthermore, for purely aesthetic reasons customers may value an underground cable differently than an overhead line. As such, spitting the capacity between the two also makes sense.

The ID dataset itself provides the length of lines (in kms) but at various voltage levels rather than on an MVA basis. The voltage levels provided in the ID dataset are shown in the table below. We need a way of summing up across these voltage levels on a consistent basis. This means we need a way of determining the MVA conversion factor associated with each voltage. We borrow the technique used for undertaking this conversion from the previous productivity study. We also understand that from an engineering perspective that at least for a high-level study aggregation using the technique previously applied is appropriate.

At a given voltage level the maximum current rating of a line depends primarily on the conductor size. Increasing the conductor size will reduce resistance and in turn increase the rated MVA of the line. However, this will increase cost as larger conductors are required and more expensive poles and towers are needed to support the increased weight. We also understand that a typical EDB is likely to use a small number of standard conductor sizes at given voltage levels, possibly only a single standard size. As such, the assumption of a single conversion factor at each voltage level does not seem so implausible. Indeed, this is exactly what the previous productivity study used.

This means we need to determine a conversion factor at each voltage level to convert what is available in the ID data to an MVA-kms basis. The previous productivity study provides a description of the conversion factors which are in turn are sourced from an older 2003 study. The description of the conversion factors in the previous productivity study don't exactly match the categories shown in the ID dataset. For example, they state "110 kV lines [were converted] using a factor of 80" while the highest voltage category in the ID dataset is "> 66kV overhead". Nonetheless, the conversion factors do broadly match other available sources. For example, North Power in their overhead line design standard provides four standard conductors at 11kV. The relevant MVA conversion factors are 3.6, 4.2, 5.2 and 7.6. This compares to the conversion factor of 4 used for 11kV lines in the previous productivity study.

Given the information available, our proposed MVA conversion factors are shown in the table below. We multiply line length at each voltage category by this conversion factor to achieve an MVA-km measure which can be summed across voltage categories.

Table 3.2: MVA conversion factor used to calculate circuit capacity by voltage level

Voltage category as in ID dataset	Proposed MVA conversion factor
> 66kV	72.5
50 kV & 66 kV	30
33 kV	15
SWER (all SWER voltages)	10
22 kV (other than SWER)	8
6.6 kV to 11 kV (inclusive – other than SWER)	4
Low voltage (< 1kV)	0.4

Source: CEPA assumptions.

Reliability

Reliability is a category of output that was not included in the previous productivity study. Reliable electricity supply is an output that customers value and EDBs have an important role in providing this service. As such, we propose to include reliability as an output. Reliability is qualitatively different than the other outputs we consider. Reliability captures something about the quality of service that differs from other outputs like number of customers served. We also make the decision to include reliability as a negative value in our index-based models. This implicitly assumes that there is a certain value of output produced which is then negatively impacted by our chosen measure of reliability.

There are of course several measures of reliability that could be used, and the information disclosure dataset provides lots of options. We made the decision to represent reliability as total minutes off supply and we aggregate both unplanned and planned minutes lost together.

Total minutes lost seems a more appropriate measure than some alternatives like number of interruptions. The impact of an interruption is likely to vary substantially suggesting the use of a static value to represent the cost of an interruption is even less valid than using a static value to represent minutes off supply. Furthermore, other recent productivity studies of electricity distribution networks have used minutes off supply.[16]

Aggregation of both planned and unplanned in one measure is more open to question. Both clearly represent service quality, a planned outage would still be seen as costly by customers. However, a planned outage would be seen as less costly than an unplanned outage. Nonetheless, for simplicity we combine both measures.

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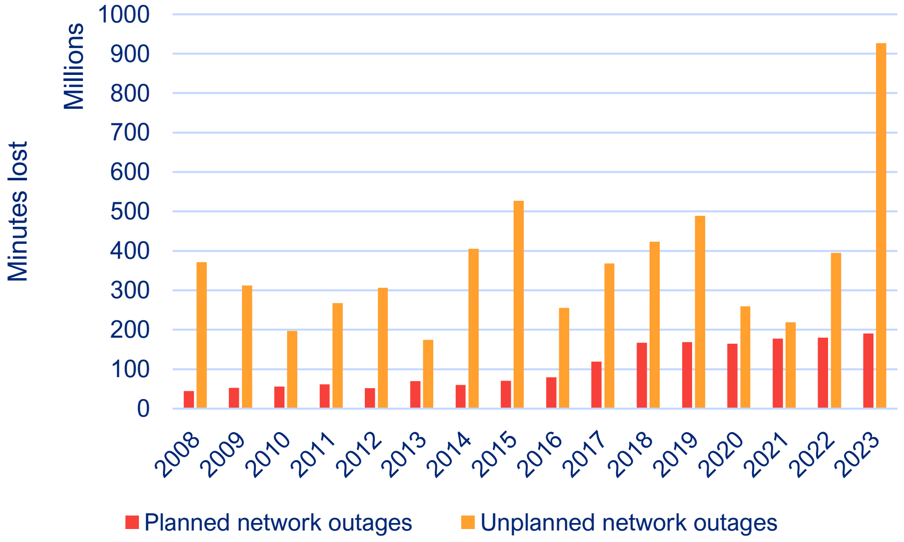
[16] For example, Quantonomics (2022).

The figure below shows how these two measures vary over time. There is a general trend upwards over the period for both types. For planned there is a step up between 2016 and 2018. For unplanned the trend upwards is less pronounced with 2023 being a clear outlier year. The general upward trend in minutes lost is maintained even after accounting for the increase in the number of customers.

The information disclosure data provides data on both SAIDI class B (planned network outages) and SAIDI class C (unplanned network outages). SAIDI represents the [sum of all customer interruption durations] / [total number of customers served]. For each EDB for both SAIDI class B and SAIDI class C we take this variable and multiply it by our measure of total customers. This recovers the sum of total customer interruption durations in minutes for the year. This becomes our variable of total minutes lost.

Figure 4: Total customer minutes lost by type



As total minutes lost is included as a negative output this means that as total minutes lost increases output decreases and by extension the productivity index decreases holding everything else constant. As the index-based methods apply a base year of 2008 changes in the productivity index caused by minutes lost are compared against this base year. If there is a reduction in minutes lost relative to 2008 there would be an increase in the productivity index.

Other data issues

In addition to the data transformations discussed above in this sub-section we cover a few additional data issues. These modifications are shown in the R code published alongside this report.

Our analysis is for the period 2008 to 2023. This is because we have consistent data published by the Commission for this period.[17] This data is published across three datafiles.

- There are some missing data points for Orion in 2011. We have interpolated the missing data using the average of 2010 and 2012.
- There are some corrections for issues arising from the de-merger of Wellington Electricity and Vector in 2009. In our data set we do not represent Wellington Electricity separately in 2008. For opex in 2009 the share between Wellington Electricity and Vector is set to the shares of opex as observed for these EDBs in 2010. The shares of maximum demand between Wellington Electricity and Vector for 2008 is set as the

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[17] Available from the Commission's website.

shares observed in 2010. This is done to ensure ratcheted maximum demand calculations are performed correctly.

- Vector sold and leased back assets in 2020. This means that that assets appear in both opening RAB and assets commissioned. For our calculations, we have reduced assets commissioned by approximately $290m to remove double counting of these assets.
- Eastland Network was renamed Firstlight Network in 2023. In our dataset the name Eastland Network is used throughout. Where there are slight differences in EDB names between the three datasets we apply a consistent naming convention.
- The number of connections for Alpine Energy is missing for 2014. We have interpolated this missing value by using the average of the values in 2013 and 2015.

Capitalisation policies may change the relative weighting of operational expenditure and flow of capital services. This could impact the analysis if there has been a change in policy in the period being examined. We are implicitly assuming no change.

Apart from the above stated adjustments, data is used as reported in the information disclosures. There appear to be some discontinuities in the data which may be due to data quality issues. However, our view is that these are unlikely to be a substantial driver of results.

We have restricted ourselves in all our models to the data available for New Zealand EDBs only. We observe that in other benchmarking/productivity studies of electricity networks a wider dataset has been used which includes data from distribution networks in New Zealand, Australia, and Ontario.[18] Our view is that the inclusion of data from other countries introduces a wide set of issues around comparability. Adjusting for these issues may not be as simple as including a dummy variable for each country. For example, the introduction of a dummy variable by country allows the average level of costs to vary by country but it does not allow the relationship between cost drivers and cost to vary. If we take customer numbers as an example the estimated parameter shows what occurs to costs if we increase customer numbers by 1%. The inclusion of country dummies does not change this interpretation and this estimate is still the average relationship across all countries. The relationship between customer numbers and costs may be unique to New Zealand.

3.1.2. Weighting of inputs

There are two inputs that need to be weighted together, operational expenditure and flow of capital services. The overall weight of these inputs in the input index are determined by their total real value. In terms of the price/quantity framework that is applied to create index numbers the ‘quantity’ of operational expenditure or flow of capital services is the nominal amount in that year divided by the relevant price index. The ‘price’ in turn is the relevant inflation index for each of these two inputs. To calculate the index over time we have calculated Fisher index numbers.[19]

3.1.3. Weighting of outputs

As discussed in section 2.1.1, ideally in an output index the weights of outputs are determined by prices. We elect to apply static prices for outputs. As explained above there may be some justification to use time-varying prices. However, in an indexed-based method it is only the changes in relative prices that matter. If there is no good basis to justify time-varying prices than we suggest that this issue is side-stepped entirely, and static prices be applied. This also means that Laspeyres, Paasche and Fisher index procedures produce identical results.

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[18] For example, Quantonomics (2022), Economic Benchmarking Results for the Australian Energy Regulator’s 2022 DNSP Annual Benchmarking Report.

[19] The “Fisher” index is the geometric mean of the Laspeyres and Paasche indices.

While the previous 2014 productivity study applied time-varying output prices, we are unsure if the procedure used actually resulted in time-varying relative output prices.

We recognise that relative prices might change over time. For this reason, we produce low and high prices for each output and report the full range of outcomes across these relative price differences.

The decision to use static prices doesn't allow us to side-step the issue of what these prices are. We still need a basis for creating these prices, even if it is only how they relate to each other that matters. We propose to use a *cost-based approach* to create these prices. The implicit assumption is that EDBs would charge their cost for output. We use the Cobb-Douglas econometric model to estimate how much EDB costs change if they increased output by one unit. This is the same model we subsequently use to estimate the productivity time trend directly. The results of this procedure are described in Section 4.2 below.

Using this procedure, we are able to estimate intuitive prices for all our outputs except reliability. We propose an alternative method for placing a price on reliability as explained in Section 4.2.

3.1.4. Measuring annualised capital costs

In this sub-section we discuss the problems with attributing sunk capital costs across time and describe our proposed approached.

Issues with sunk costs

Our productivity assessment uses the period of one year as its unit of analysis. This presents no problem when the capital inputs used by the firm can be hired each year. In this case the relevant capital cost is the rental cost of capital. However, as discussed in section 2.3.2, the presence of sunk long-lived investments gives rise to a key problem in assessing productivity change.

This problem arises because the period of the productivity assessment (typically one year) is shorter than the length of the life of the investments. This means that some proportion of the costs of the sunk long-lived investments must be allocated to the period in question. That allocation is largely arbitrary – in that there are a large number of different allocations which could all be justifiable.

For example, in a context in which demand for network services is increasing rapidly, it may make sense to allocate the costs of a major network investment in a way which allocates more of the cost of that investment to the later years of the life of the investment (when demand for, and utilisation of the asset will be higher). Conversely, if a part of the network services, say, an aluminium smelter, which is due to close in five years' time, it makes sense to allocate the costs of that part of the network to the remaining five years' life.

In practice, however, we do not have information on the remaining economic life or demand for different parts of the network. We will, instead, assume the network is in a steady state in which capital is being replaced when it retires. In this context the annualised cost of capital can be proxied as the sum of the return on, and return of, capital. As described in the next section.

Our approach

We need to create a variable which represents the flow of capital of services on an annualised basis. We propose the following high-level principles to create this variable:

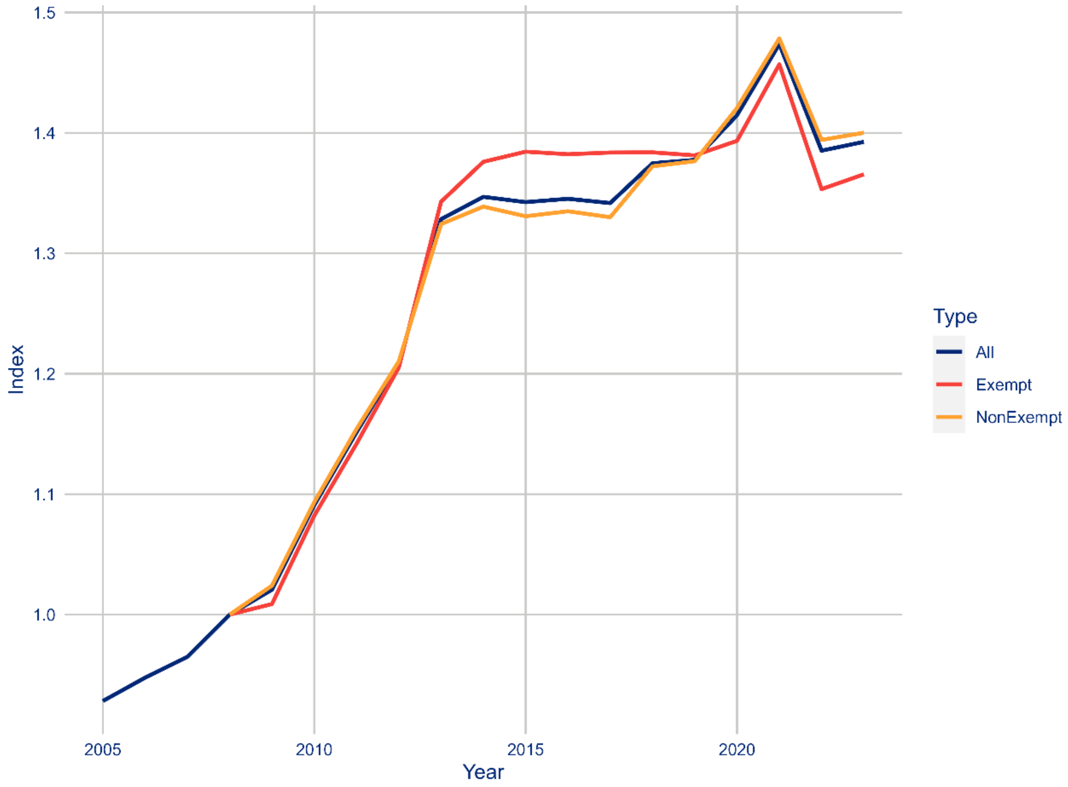
- The flow of capital services on an annual basis is assumed to be proportional to the productive capital stock, as proxied by the size of the Regulatory Asset Base.
- To estimate the total rental cost of capital, we use the approach in the previous productivity study – this involves applying an 'amortisation-based annual user cost of capital'. This consists of the sum of the 'return on' and 'return of' capital. The return on is estimated as a cost of capital multiplied by the regulatory asset

base. In our base case, the cost of capital is assumed to be 5.6% over the entire period.[20] The return of capital is equal to the depreciation as reported in the information disclosure data.

The value of capital assets can appreciate over time. Our understanding is that the Commission applies an indexed RAB approach. This means that asset values that make up the RAB are indexed upwards for inflation in each period. We assume that the indexation adjustment as applied in the information disclosure dataset is the correct asset price inflation measure.

The figure below shows our annual capital charge over time between 2005 and 2023.

Figure 5: Capital services index



Source: CEPA analysis of Commerce Commission ID data.

There are a range of assumptions used to create this index. One of the crucial assumptions is the assumed cost of capital and our decision to maintain it at the same level for the entire period. We observe the assumption of a static cost of capital is in line with other productivity studies such as the previous one commissioned by the Commission in 2014.

A static cost of capital may be appropriate. If we were to allow the cost of capital to vary then if, say, interest rates were increasing over the period, the annualised cost of capital would be increasing, and the total annualised cost (the input index) would be increasing over the period. Other things equal, this would make EDBs appear less productive, for no fault of their own. This seems misleading. Conversely, if interest rates were decreasing over the period, the annualised cost of EDBs may be decreasing, making them appear more productive, again without any action on the EDBs.

In the long run, if there is a long-term change in the cost of capital, this can be reflected in capex-opex substitution, which should be taken into account in productivity analysis. However, in the short-run there is little opportunity to change the (largely sunk) capital base of an EDB. Our preference is to apply a static cost of capital.

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[20] This is the mid-point post-tax WACC for EDBs as determined by the Commission for disclosure year 2024.

3.2. ECONOMETRIC ESTIMATION

In addition to the indexed-based methods we also estimated econometric models of both total cost and operating cost functions.

A cost function represents how the combination of outputs impacts cost. In estimating these cost functions we must make assumptions about the shape of the cost functions and (therefore) the parameters to be estimated. As in previous studies we will assume that these cost functions take the forms known as Cobb-Douglas and Translog. For our econometric methods we consider the same output specifications as for our indexed-based methods.

The key difference between Cobb-Douglas and Translog is in how outputs are assumed to impact cost. Cobb-Douglas assumes a simpler relationship between outputs and cost. It assumes that costs are determined by multiplying outputs together raised to a certain exponent. This can be seen in the first formula below. The Translog functional form allows for a broader range of relationships between outputs and cost. For example, it includes interaction terms where the combined effect of two outputs on cost can be captured. It allows for the possibility that the combined effect of two outputs has a greater effect on cost than their individual effects.

The formula below sets out the Cobb-Douglas cost function we estimate. Cost is assumed to be proportional to the product of each output raised to a power. The power is a parameter which we seek to estimate. The constant of proportionality is the total factor productivity.

$$C = A \,.\, \Pi_{i=1}^{M} X_i^{\beta i}$$

Here C is the total annualised cost, X_i is the *i*th output and β_i is the power on the *i*th output. Where we estimate opex partial productivity C is opex. Costs are represented in real terms as they have been deflated for assumed input prices.

This Cobb-Douglas form is convenient as it becomes linear when we take logs of each side of the equation. After taking logs means each output term is no longer multiplied together to determine cost but simply added. This means we can simply use ordinary least squares to estimate each elasticity. This yields the following equation:

$$c_{jt} = \beta_o + \sum_{i=1}^{M} \beta_i \, x_{jit} + \beta_{M+1} t + D_j + v_{jt}$$

Here:

- c_{jt} is the In of the cost of firm j at time t.
- β_o is a constant term
- β_i is the power[21] (the elasticity) of output i
- x_{jit} is the In of the output I of firm j at time t
- The coefficient on t is the time trend,
- D_j reflects firm specific factors (an EDB ‘dummy variable’)
- v_{jt} is an error term

We use this model for two purposes. Firstly, we use the coefficient estimates to recover output prices which are used in our index-based methods. Secondly, we this model to directly estimate the coefficient on time t, which reflects how total factor productivity changes over time.

The time trend variable captures changes in costs not explained by the other variables included. A time trend coefficient of 0.02 indicates that, if outputs were to remain constant across a year, costs would increase by 2%.

The Cobb-Douglas functional form is very commonly used in economics, both for representing cost functions and production functions. Another commonly used form is Translog, which is shown in log form below.

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[21] The sum of βs provides an indication of scale impacts.

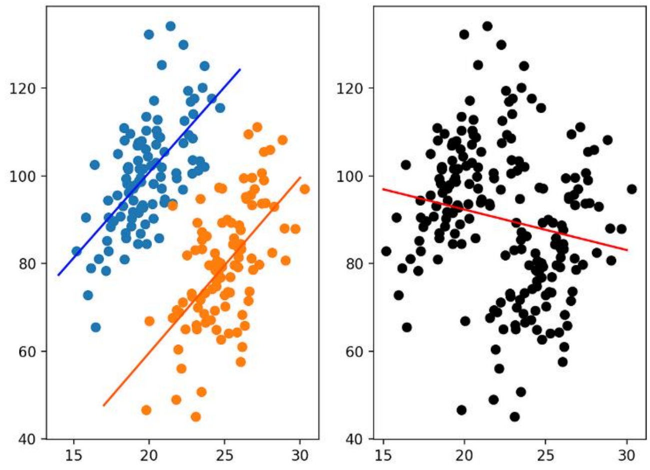
$$C_{jt} = \beta_o + \sum_{i=1}^{M} \beta_i \, x_{jit} + 0.5 \sum_{i=1}^{M} \sum_{i=1}^{M} \beta_i \, x_{jit} \, x_{jit} + \beta_{M+1} t + D_j + v_{jt}$$

The simpler Cobb-Douglas functional form can be estimated using a regression with all parameters in logs and no interaction terms, implying that the elasticities of costs to each output are constant regardless of the level of outputs. The translog functional form includes interaction terms between variables, allowing the elasticity of costs to each output to vary with the level of the output. Further details of the econometric estimation approach and these functional forms are provided in Appendix B.

As well as using two different functional forms, we have also, under each of these, run the models with and without dummy variables for each EDB, or in other words EDB fixed effects (FE). In the formulas above this is represented by the term D. This dummy variable captures the estimated cost impact of each EDB, assuming that the effects of unchanging, unobserved variables can be captured by an EDB-specific dummy variable. In this report we have not set out to consider or benchmark the relative productivity of EDBs, however, the introduction of FE changes the interpretation and value of the other variables. Without FE, the estimates look "across" the data, whilst with the inclusion of EDB FE the estimates instead look "within" the EDBs. This is demonstrated in Box 2 below.

Box 2: Fixed effects

The figure below demonstrates how the regression line changes with the introduction of EDB dummies. With the pooled dataset the estimate is across all the data as shown in the panel on the right. With the introduction of EDB dummies the average position of the line is allowed to vary as shown in the panel on the left. The regression lines in the left panel run parallel to each other. This is the correct representation as there is still only a single parameter estimate of the impact on cost, for example, how much costs change if customer numbers are increased.



Source: Copeland (2020)

4. RESULTS FROM INDEXED-BASED APPROACHES

This section presents our results from applying an indexed-based approach. We set out our input index, our output index and the resulting productivity index. We do this for the industry overall, exempt EDBs and non-exempt EDBs. We also present a total factor productivity index as well as an opex partial factor productivity index.

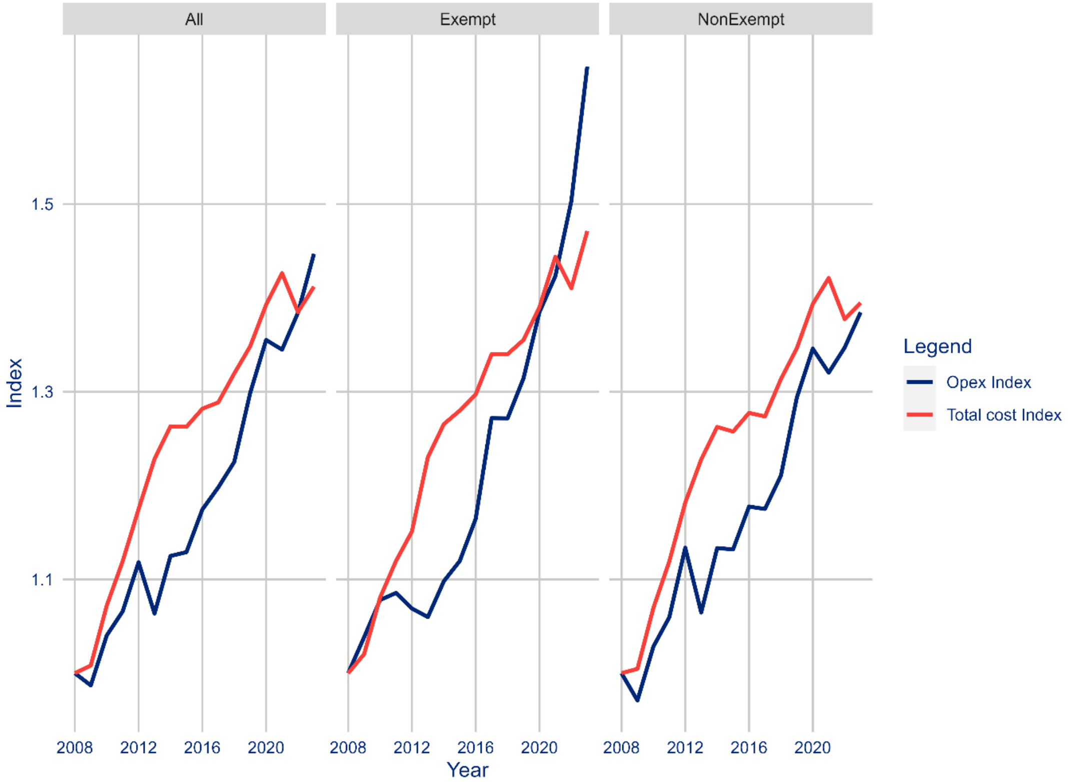
4.1. INPUT INDICES

We construct two input indices, a total expenditure index made up of opex and flow of capital services and an index containing opex only. These are shown in the figure below which is split into three panels showing the overall industry, exempt EDBs and non-exempt EDBs. The red line shows total expenditure and the blue line opex.

The overall total expenditure of non-exempt networks is substantially larger than exempt EDBs. This means that the overall industry picture is driven by non-exempt EDBs. For non-exempt EDBs, and by extension the industry overall, the flow of capital services grows faster early in the period but opex growth accelerates as we proceed towards the present. The ending positions of both indices are very similar with the overall index being 41% higher in 2023 than in 2008 and the opex index 45% higher.

There is a marked difference in growth between exempt and non-exempt EDBs. This is particularly the case for opex, opex for exempt EDBs is 64% higher in 2023 relative to 2008 while this value is just 38% for non-exempt EDBs. This doesn't necessarily mean that productivity growth is worse for exempt EDBs as it is possible that outputs may have also grown more quickly. This is explored further in Section 4.3 below.

Figure 6: Input indices (all, exempt, non-exempt)

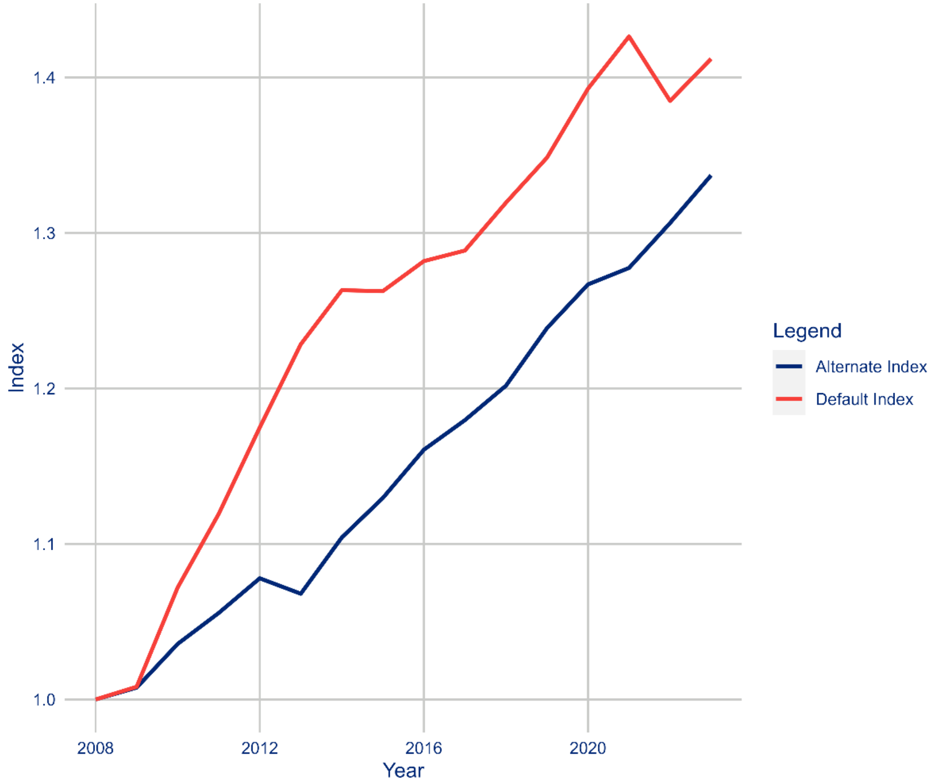


Source: CEPA analysis of Commerce Commission ID data.

In Section 3.1.1 we explained that we are not using the same specification for capital inputs as used in the 2014 study. In 2014 capital input quantities were used to construct the capital input index. Specifically, transformer capacity, overhead line capacity and underground cable capacity.

The figure below shows what the overall index would have been following the previous method (blue line, labelled alternate index).[22] Under this methodology inputs have grown less quickly than under our proposed approach.

Figure 7: Input index – Comparison of input index methods



Note: Default index is the index we use in this productivity study. Alternate index is the index that would result if treating capital inputs in the same way as the 2014 productivity study by Economic Insights.

Source: CEPA analysis of Commerce Commission ID data.

4.2. OUTPUT INDICES

We considered a wide range of output specifications. In total we report nine different specifications of output as shown in the table below. Output specifications 1 to 3 are the same output specifications tested by Economic Insights in 2014. As such, the justification for their inclusion is simply continuity with what was attempted previously.

We test a series of additional output specifications. While it is possible to attempt a wider range of output combinations, we have restricted our reporting to 9 primarily to make presentation of results tractable. Furthermore, in an indexed-based method the maximum and minimum positions are defined by the maximum and minimum changes in the individual outputs. This means that there is a limited range of different productivity-index results that can be produced by switching outputs in and out. On the individual models we provide some logic for their inclusion in our set of 9:

- **Models 1-3**: We included these because they were tested by Economic Insights in 2014.
- **Model 4**: This is the same as model 3 except energy delivered is not included as there is clear debate regarding whether it is an appropriate output or proxy output for an EDB.

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[22] We have attempted to implement the same approach as Economic Insight's 2014 approach. In terms of high-level methodology, we confident we have done so. However, there may be some implementation differences. For example, the way in which capacity in MVA-kms were determined.

- **Model 5**: This is the same as model 1 except reliability has been included.
- **Model 6**: Similar to model 3 but with a different series of outputs included alongside ratcheted maximum demand.
- **Model 7**: Same as model 6 but with transformer capacity dropped.
- **Model 8**: The same as model 1 but circuit length is represented by length-capacity (in MVA-kms) and split between overhead and underground.
- **Model 9**: Same as model 7 but circuit length is represented by length-capacity (in MVA-kms) and split between overhead and underground.

Table 4.1: Output specifications

Model number	Number of outputs	Outputs
1	2	• Circuit length (kms) • Customer numbers
2	3	• Energy delivered (GWh) • Customer numbers • Transformer capacity (MVA)
3	4	• Energy delivered • Ratcheted maximum demand • Customer numbers • Circuit length
4	3	• Ratcheted maximum demand • Customer numbers • Circuit length
5	3	• Circuit length • Connections • Reliability – Total minutes lost
6	3	• Ratcheted maximum demand • Circuit length • Transformer capacity
7	2	• Ratcheted maximum demand • Circuit length
8	3	• Customer numbers • Overhead line capacity (MVA-kms) • Underground cable capacity (MVA-kms)
9	3	• Ratcheted maximum demand • Overhead line capacity • Underground cable capacity

4.2.1. Output prices

To produce an output index, we need to define the relative weights assigned to each output. In a productivity analysis these weights are often defined by prices. We propose to use the outputs of a Cobb-Douglas cost model to determine output prices and by extension weights. These re-purpose an output of the model which we are using to estimate productivity directly in Section 5. The key assumption here is that costs can adequately represent prices or at least that costs can adequately represent *relative* prices.

There are some modelling decisions that need to be made with implementing our Cobb-Douglas cost models to estimate output prices. One of these is whether to include dummy variables for each EDB or in other words EDB fixed effects (FE). This dummy variable captures the model's estimated cost impact for each EDB. In this report we have not set out to consider or benchmark the relative productivity of EDBs and do not report these results. However, introduction of EDB dummies changes the interpretation and value of the other variables. Without EDB dummies the estimates look "across" the data while the inclusion of EDB dummies they look "within" the EDB. For example, for model 2 customer numbers are significant driver of costs across EDBs. This is not a surprising finding, the more customers an EDB has larger its costs. However, the variable turns insignificant with EDB dummies suggesting that within an EDB customer numbers after controlling for energy delivered and transformer capacity is not a significant driver of cost.

Our primary purpose with these models in the first instance is to recover appropriate output prices for use in our output index. The key assumption being that costs set prices. As such, we intend to use the range of modelled values for our output index.

The table below shows the estimated output prices by model.[23] Output prices in the previous 2014 productivity study were presented in terms of percentage of revenue which were also ultimately estimated from a cost model. This percentage of revenue was then divided by the output in each year to retrieve time-varying prices. The prices themselves were never presented in the actual report but are recoverable from the analytical files. While we present the prices it is possible to present these numbers in a similar way to that of Economic Insights (2014). For example, for model 1 we find cost weights with 58%/42% of total cost being determined by circuit length/ICPs respectively. This is relative to Economic Insights 2014 finding for 54%/46% circuit length/ICPs. The similarities do however seem to end at model 1.

Our primary purpose with the estimated prices is to use them as weights in our index-based approach. For this we are applying judgement rather than directly using the modelled outputs. In Table 4.3 below we provide the price ranges we are using for each output. We consider that these cover an adequate range of potential prices. We are rejecting modelled outputs where they are negative. These do not make intuitive sense in the context of the index-based approach. For example, if the variable on energy delivered were negative this would mean that customers have reduced value from the network as the amount of energy delivered increases.

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[23] We estimated the Cobb-Douglas models using a log-log regression specification. Output prices have been recovered by taking the partial derivative of cost with respect to each output. For example, for circuit length, aC/L, where a is the elasticity for circuit length, C is total cost and L is circuit length.

Table 4.2: Output price by model

Model number	Output	Prices	Prices - FE
1	Circuit length	$3,152*	$2,080*
	ICPs	$321*	$202*
2	Energy	-$3,747	$12,802*
	ICPs	$161*	-$70
	Capacity	$40,869*	$15,131*
3	Energy	-$2,838	$9,998*
	Ratch. Max.	$55,864*	$80,639*
	ICPs	$181*	-$90
	Circuit length	$3,196*	$2,981*
4	Ratch. Max.	$44,929*	$109,858*
	ICPs	$178*	-$15
	Circuit length	$3,116*	$3,077*
5	Circuit length	$2,952*	$2,066*
	Connections	$321*	$188*
	SAIDI B	$0.144	$0.078
	SAIDI C	$0.023	$0.025
6	Ratch. Max.	$47,495*	$89,694*
	Circuit length	$2,932*	$2,468*
	Capacity	$18,419*	$9,589
7	Ratch. Max.	$91,463*	$108,787
	Circuit length	$3,500*	$3,020
8	ICPs	$319	$84
	Overhead [24]	$373	$316
	Underground	$1,912	$1,138
9	Ratch. Max	$84,508	$87,890
	Overhead	$409	$277
	Underground	$2,454	$770

Source: CEPA analysis of Commerce Commission ID data.

** Significant at at least < 5%.*

Reliability

We have been unable to recover intuitive estimates for reliability from our econometric cost models. We tested both using raw minutes lost and normalised values. Normalised values are available from the ID dataset from 2013 onwards, which reports normalized SAIDI class B and C numbers together. Our understanding is that normalized reliability removes the impact of major events. When SAIDI on a particular day exceeds a certain "boundary value" that day's SAIDI value is instead replaced by the boundary value.[25]

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[24] MVA-kms

[25] NZCC (2022), Electricity Distribution Information Disclosure (Targeted Review Tranche 1) Amendment Determination, attachment B.

The models we tested either produced insignificant coefficients or coefficients which appear to have the incorrect sign. The input into our models is total minutes lost.[26] If a positive coefficient is found this suggests it costs EDBs money to become more unreliable. We suspect that these models suffer from the impact of another factor which is not accounted for. This factor pushes up both costs and minutes lost and if not corrected for makes it look like providing unreliability is costly. One such factor is weather events such as cyclones.

As we are unable to estimate an intuitive cost-based price we need an alternative for reliability. In our draft report we used an Australian estimate for the value of customer reliability (VCR). We recognize that estimates derived from New Zealand data are preferable. We identified a study undertaken by Transpower in 2018 which estimated the value of lost load.[27] Transpower appointed PWC to estimate VoLL in 2018 and we propose to use their estimate.[28]

VoLL is reported by Transpower in terms of $/MWh. We represent reliability in terms of minutes lost. In our draft report we converted Australian estimates which were also in terms of $/MWh to $/minute using average energy delivered per minute. While Transpower reports value of lost load in $/MWh, the PWC study allows us to skip this conversion step as in addition they report $/outages which act as an input into their $/MWh VoLL values. Outages are defined in terms of time and include a 10 minute, 1 hour, 5 hour and 8 hour outage.

PWC report baseline values for willingness to pay (WTP) and willingness to accept (WTA) an outage. We understand the baseline to mean a 1-hour outage in winter on an evening. We have converted these numbers to 2005 real figures and report them per minute in the table below.

Table 4.3: Estimates of Willingness to Pay (WTP) and Willingness to Accept (WTA) outages

Customer type	WTP – PWC reported	WTA – PWC reported	WTP per minute (2005 real)	WTA per minute (2005 real)
Residential	$10.79	$43.89	$0.14	$0.57
Primary, small	$183.97	$541.40	$2.39	$7.03
Industrial, small	$114.28	$826.76	$1.48	$10.74
Commercial, small	$94.71	$328.37	$1.23	$4.26
Primary, large	$589.44	$1,168.88	$7.65	$15.18
Industrial, large	$447.90	$3,862.30	$5.82	$50.18
Commercial, large	$383.29	$3,406.87	$4.98	$44.27

Our previous methodology using Australian values resulted in a residential value of $0.54 per minute off supply. This is within the range reported by PWC for residential customers in New Zealand i.e. $0.14 to $0.57.

The PWC report demonstrates that several factors impact the prices assigned to an outage. These include the type of customer, when the power cut occurs and the length of the outage. One of the issues that is not covered in the PWC report is the difference between a planned and an unplanned outage. NZIER suggest that the difference could be substantial with an unplanned outage VOLL of $25,000 per MWh but planned outages having a VoLL in “the

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[26] We tested total planned and unplanned together and separately.

[27] Transpower (2018), Value of Lost Load Study.

[28] PWC (2018), Estimating the Value of Lost Load in New Zealand.

order of ‘tens of dollars per MWh’”.[29] This suggests a planned outage may only be worth around $0.001 per minute off supply, which is much lower than our low-end sensitivity in our draft report of $0.01.[30]

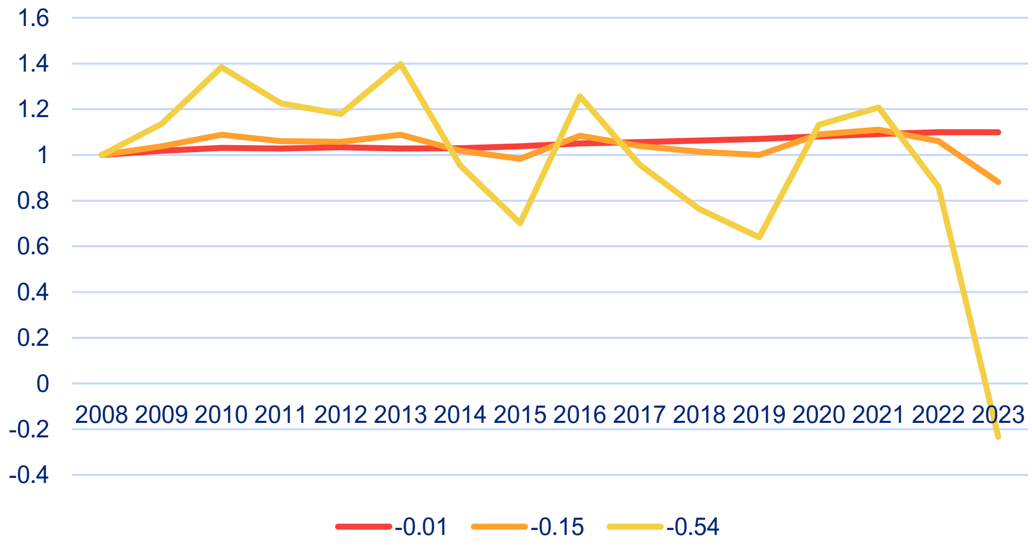
The other issue that we had to address at the draft report was converting the VCR value into a ‘cost-based’ value. This is because all other parameters enter our model in terms of EDB costs, with the assumption that relative costs represent relative prices. The VoLL value is instead based on consumer surplus or in other words the total value lost to the customer from being off supply. Likewise, the value of a customer connection is much higher than our estimated EDB cost of providing that connection. As the VoLL value is likely to be substantially higher than cost simply introducing it into the model without adjustment is inappropriate.

The draft report method applied a 28% adjustment factor, that is the value used in our models was 28% of the VCR value.

The figure below shows the substantial range of output index positions that are achieved by varying the price of reliability. This shows the output index for a model that includes customer numbers, circuit length and minutes lost. To produce the largest impact, we have used our lowest prices for customer numbers and circuit length which are $2000 and $100 respectively. As there was a large number of minutes lost in 2023 relative to 2008 an assumption of a price of -$0.54 per minute lost leads to an odd conclusion that EDB output has fallen away entirely.

While minutes lost in 2023 was high relative to previous years it was still just 495 minutes per customer or 0.09% of the year. In terms of time, EDB reliability was still above 99.9%. As such, using a price of -$0.54 seems to produce an outcome not in line with our intuition. The direct use of a VCR value here is clearly not appropriate and this suggests the direct use of VCR values as prices in other similar productivity studies may also be open to question.

Figure 8: Impact of reliability price assumption on output index



Source: CEPA analysis of Commerce Commission ID data and AER data.

Our draft report used a price of -$0.15 which involved adjusting the -$0.54 so it was in line with our modelled cost-based prices. Our proposed adjustment was as follows:

- We assume that the -$0.54 VCR should be seen in the context of total payments by customers for electricity network services which is represented by EDB total revenue.

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[29] NZIER (2019), Comment on Transpower RCP3 Submission.

[30] This can be derived in two ways. Taking the residential figure of $0.73/minute and multiplying it by the ratio of VOLLs ($50:$25000) provides $0.0014/minute. Alternatively, the average EDB customer consumption over the period is $0.03 KWh/minute which when multiplied by a VOLL of $50/MWh results in $0.0015/minute.

- If we use the modelled cost-based prices of circuit length and customer numbers multiplied by actual observed circuit length and customer numbers we find that this is on average 28% of EDB revenue over the period.
- We scale -$0.54 by 28% to produce a price of -$0.15.

Our second proposal was for a low-end sensitivity with a value of -$0.01.

Given that the New Zealand based VoLL estimates are in the same ballpark as the Australian based estimates we used at the draft report we propose to maintain the draft report prices.

Summary of prices

Given these results and the purpose of this section to recover prices for outputs rather than identify drivers of cost we have applied some judgement to create price ranges as shown in the table below.

Table 4.4: Proposed min-max output prices

Output	Proposed price range
Circuit length (kms)	$2000 - $4000
Customer numbers	$100 - $400
Energy (GWh)	$13,000 - $16,000
Transformer capacity (MVA)	$8,000 - $42,000
Ratcheted maximum demand (GW)	$47,000 - $110,000
Reliability (Minutes lost)	$-0.01 - $-0.15
Overhead line capacity (MVA-kms)	$300 - $450
Underground cable capacity (MVA-kms)	$600 – $2,400

Source: CEPA analysis of Commerce Commission ID data.

4.2.2. Output indices

In this section we present the output indices for the various combinations of outputs. We apply a low and a high price for each output, as shown in the table in the section above. This combination creates a minimum and maximum position in each year with variation achieved by the different output prices. This is because prices determine weights in the output index.

The overall range is limited with the largest variation achieved by placing complete weight on one or other output. For example, in model 1 customer numbers grow faster than circuit length. The maximum achievable position in 2023 for the model 1 output index is achieved by assuming a very high price on customer numbers relative to circuit length. This simple intuition does not hold when negative prices are introduced into the index, which we do for model 5 where we have included reliability. We discuss the outcome of adjusting for reliability further below.

The table below shows the output index positions in 2023 for each of our models for the industry overall, exempt EDBs and non-exempt EDBs. We also present the output indices as figures in Appendix D, which allows an examination of the trends over time.

Putting aside the reliability model, which we discuss below, our observations on the output indices are as follows:

- The output specification that produces the lowest growth is model 1. This defines EDB output as circuit length and number of customers served. Both of these outputs have grown slowly relative to other outputs.
- The output specification that produces the highest growth is model 9. This is primarily because credit is given for expanding underground cable capacity which has grown at a faster rate relative to other outputs.

- Between 2008 and 2023 the output indices we constructed grew by between 11% and 26% industry wide, for exempt EDBs this was between 10% and 32% and for non-exempt EDBs between 10% and 24%. In general output for exempt EDBs grew faster than for non-exempt EDBs.

Table 4.5: Output index in 2023 minimum/maximum

Model	All: Min/Max	Exempt: Min/Max	Non-exempt: Min/Max
Model 1: Circuit length/customer numbers	1.10/1.14	1.10/1.16	1.10/1.13
Model 2: Energy delivered, customer numbers, transformer capacity.	1.18/1.26	1.19/1.30	1.17/1.24
Model 3: Energy delivered, ratcheted maximum demand, customer numbers, circuit length.	1.13/1.16	1.14/1.19	1.12/1.15
Model 4: Ratcheted maximum demand, customer numbers, circuit length.	1.12/1.16	1.14/1.21	1.12/1.14
Model 5: Circuit length, connections, reliability	0.88/1.13	0.98/1.15	0.85/1.12
Model 6: Ratcheted maximum demand, circuit length, transformer capacity	1.15/1.24	1.16/1.29	1.14/1.23
Model 7: Ratcheted maximum demand, circuit length	1.12/1.16	1.13/1.21	1.11/1.14
Model 8: Customer numbers, overhead line capacity, underground cable capacity	1.16/1.24	1.18/1.30	1.15/1.22
Model 9: Ratcheted maximum demand, overhead line capacity, underground cable capacity	1.18/1.24	1.21/1.33	1.16/1.22

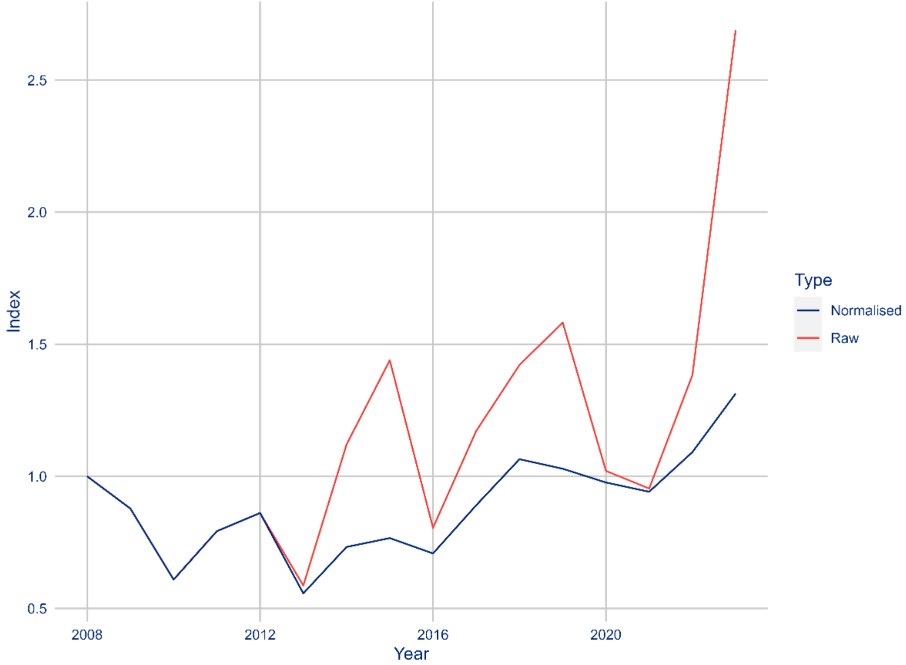
Source: CEPA analysis of Commerce Commission ID data.

Reliability

In our draft report we only looked at raw minutes off supply. In addition, we have now considered normalised reliability. As described above, this removes (or at least reduces) the impact of major events on minutes lost. The figure below shows the difference between minutes lost on a raw and a normalised basis indexed to 2008. Raw and normalised reliability are identical until 2013 because the ID dataset does not provide normalised numbers pre-2013.

We observe that even on a normalised basis minutes lost are higher in 2023 than in 2008. However, the trend in the intervening period is different. While the raw minutes lost number is volatile and generally above the 2008 number the normalised number is not only less volatile it is generally below the 2008 number. Nonetheless, there remains a general upward trend since 2013.

Figure 9: Index of reliability – Raw numbers and normalised



Source: CEPA analysis of Commerce Commission ID data.

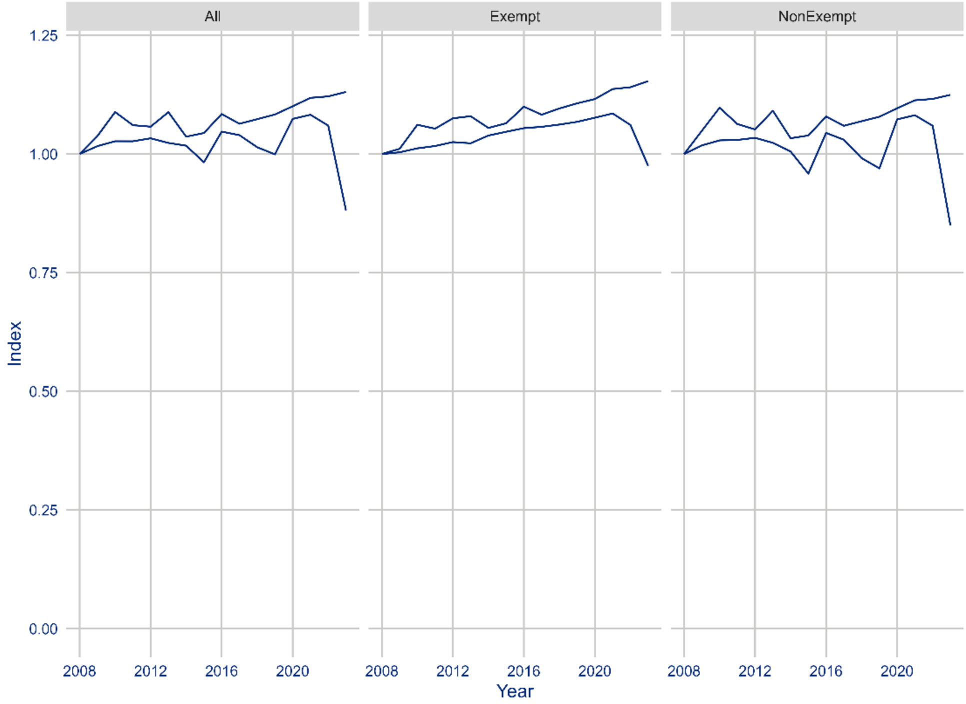
As both raw and normalised minutes lost numbers are higher in 2023 than in 2008 we find that the inclusion of reliability reduces the output index. This in turn will mean that the corresponding productivity index will also be reduced. The figure below shows the output index for the model which includes circuit length, connections, and reliability. The two lines on each figure represent the minimum and maximum positions depending on the prices.

Using raw minutes lost, the impact on the output index is limited when a low negative price for reliability is applied ($-0.01). For the industry overall the output index position in 2023 is 1.13 compared to 1.14 which where it would have been without including reliability. Our high price of reliability of $-0.15 leads to rather dramatically different results. The output index position in 2023 is 0.88 suggesting that industry-wide output has fallen significantly since 2008. This fall would be attributed to the increase in minutes lost in 2023.

This is not the case with normalised values where the impact of the substantial increase in minutes lost in 2023 is barely visible.

We have not attempted to include reliability in our other output models. This is simply because the conclusions would be similar. If our low price for reliability were used our output index would show slightly lower output with reliability accounted for than without. If our high price for reliability were used than the 2023 position is almost entirely determined by reliability and would be lower than 2008. As such, our conclusion on reliability is less certain. All we can say confidently is the inclusion of reliability would reduce our output index. This is because minutes lost is higher in 2023 relative to 2008. If minutes lost had decreased then the inclusion of reliability would lead to the opposite finding. As it is difficult to confidently attribute a price to reliability it is difficult to say by how much the output index has reduced.

Figure 10: Model 5 (Circuit length, Connections, reliability)



Source: CEPA analysis of Commerce Commission ID data.

Figure 11: Model 5 (Circuit length, Connections, normalised reliability)

4.3. PRODUCTIVITY INDICES

In this section we provide the productivity indices for each output specification. Productivity indices are reported for both total factor productivity, which includes both opex and flow of capital services and opex partial factor productivity.

We report the results for a range of output specifications. However, all output specifications that don't include reliability produce a similar trend. Figure 12 below shows the average total factor productivity index for the industry overall across all non-reliability output specifications. The productivity index falls to 2014 and then stabilises. The level it stabilises at depends on the output specification chosen but on average this is approximately 0.8. The productivity index has effectively held steady for almost ten years.

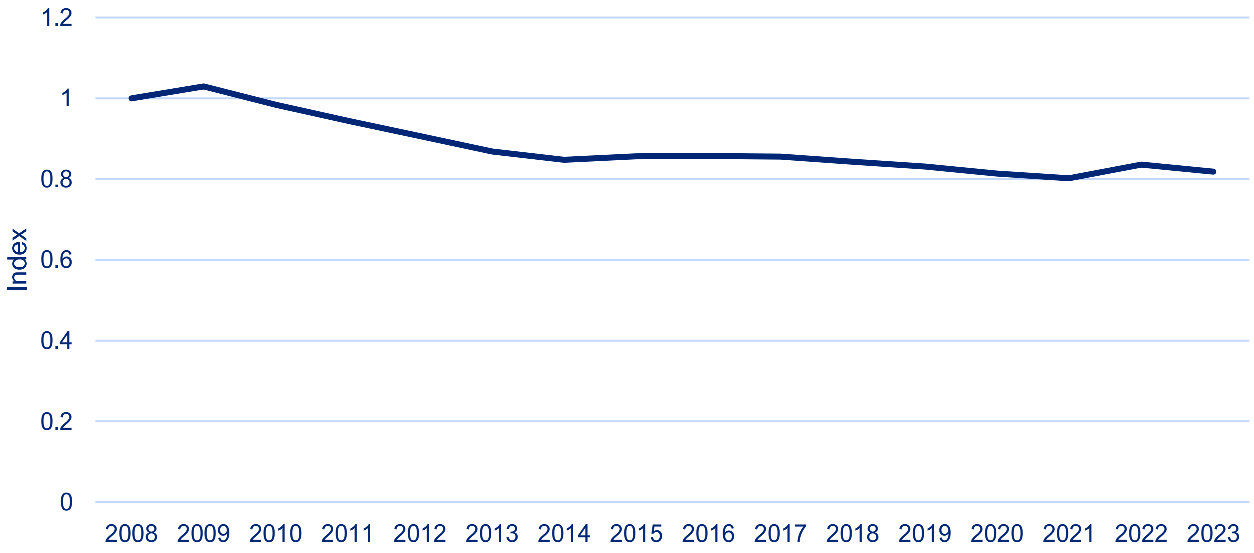
The previous productivity study commissioned by the Commission in 2014 also found their productivity index to fall between 2004 and 2014.[31] Our findings do not contradict this, with a decline in the productivity index observable between 2008 and 2014.

The opex partial factor productivity index shows a different trend than the total factor productivity index. Relative to opex there is rapid growth in the flow of capital services index in the period 2008 to 2014. However, the relationship flips in the period 2015 to 2023 with faster opex index growth relative to flow of capital services index growth. The ultimate ending positions of the two indices in 2023, at least for the industry overall, are very similar.

In terms of the opex partial productivity index there are differences between non-exempt and exempt EDBs. This is demonstrated in Figure 13 below which shows the productivity indices for model 1. The opex partial productivity index is shown as the blue line and for exempt EDBs there is a more substantial drop-off in the more recent period. The opex partial productivity 2023 index position on average across non-reliability output models is between 0.70 and 0.75 for exempt EDBs and 0.82 and 0.86 for non-exempt EDBs.

We tested what the trend and ending position would have been had we used the alternate definition of capital inputs. This is where capital inputs were proxied by quantities of transformer capacity, overhead line capacity and underground cable capacity. We tested this for the model 1 output specification. We find that the total factor productivity index still falls under this methodology. However, the trend is more continuously down over the period rather than down and then stable. The ending positions are higher than under our proposed methodology. Our ending index positions under model 1 in 2023 are 0.78/0.80. This compares to 0.82/0.85 under the alternate capital inputs methodology.

Figure 12: Average total factor productivity index – Overall industry – Not including reliability[32]



Source: CEPA analysis of Commerce Commission ID data.

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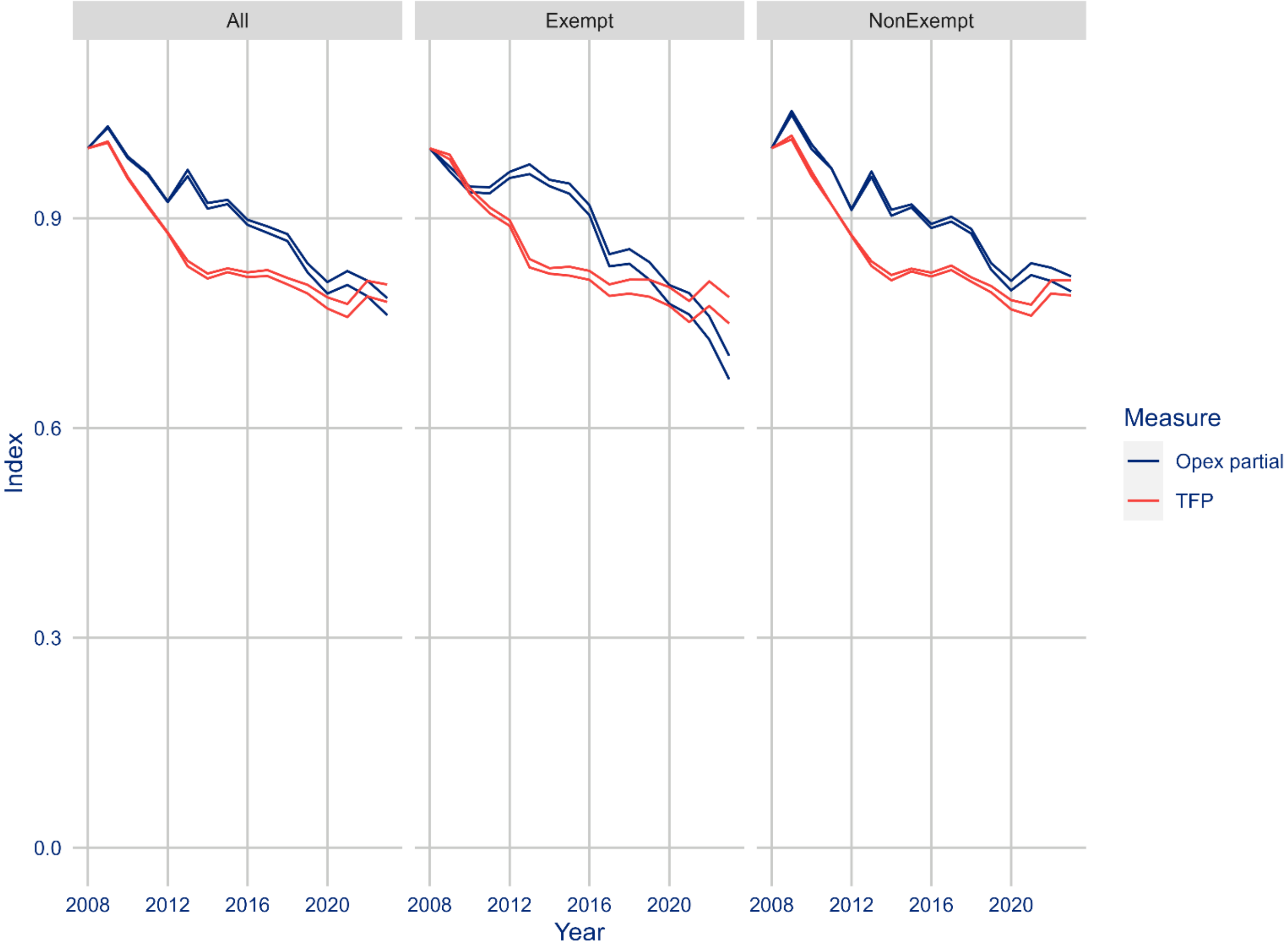
[31] Economic Insights (2014), Electricity Distribution Industry Productivity Analysis: 1996-2014.

[32] Figure takes the average of the mid-point between min/max of all output specifications except model 5 in each year.

Figure 13: Model 1 - Productivity indices (Output: Circuit length/ICPs)



Source: CEPA analysis of Commerce Commission ID data.

Table 4.6: Total factor productivity index in 2023 minimum/maximum

Model	All: Min	All: Max	Exempt: Min	Exempt: Max	Non-exempt: Min	Non-Exempt Max
Model 1: Circuit length/customer numbers	0.78	0.80	0.75	0.78	0.79	0.81
Model 2: Energy/customer numbers/capacity	0.83	0.89	0.81	0.88	0.84	0.89
Model 3: Energy/ratcheted max. demand/customer numbers/circuit length	0.80	0.82	0.77	0.81	0.81	0.82
Model 4: Ratcheted max. demand/customer numbers/circuit length	0.79	0.82	0.77	0.82	0.80	0.82
Model 5: Circuit length/customer numbers/reliability	0.62	0.80	0.66	0.78	0.61	0.81
Model 6: Ratcheted maximum demand/circuit length/capacity	0.81	0.88	0.79	0.88	0.82	0.88
Model 7: Ratcheted max. demand/ circuit length	0.79	0.82	0.77	0.82	0.80	0.82
Model 8: Customer numbers/overhead/ underground	0.82	0.87	0.80	0.88	0.82	0.87
Model 9: Ratcheted max. demand/overhead/ underground	0.83	0.88	0.82	0.90	0.83	0.87
Average across specifications (non-reliability)	**0.81**	**0.85**	**0.78**	**0.85**	**0.81**	**0.85**

Source: CEPA analysis of Commerce Commission ID data.

Table 4.7: Opex partial productivity index positions in 2023 minimum/maximum

Model	All: Min	All: Max	Exempt: Min	Exempt: Max	Non-exempt: Min	Non-Exempt Max
Model 1: Circuit length/customer numbers	0.76	0.79	0.67	0.70	0.80	0.82
Model 2: Energy/customer numbers/capacity	0.81	0.87	0.73	0.79	0.84	0.90
Model 3: Energy/ratcheted max. demand/customer numbers/circuit length	0.78	0.80	0.69	0.72	0.81	0.83
Model 4: Ratcheted max. demand/customer numbers/circuit length	0.78	0.80	0.69	0.73	0.81	0.83
Model 5: Circuit length/customer numbers/reliability	0.61	0.78	0.59	0.70	0.61	0.81
Model 6: Ratcheted maximum demand/circuit length/capacity	0.79	0.86	0.71	0.79	0.83	0.89
Model 7: Ratcheted max. demand/ circuit length	0.77	0.80	0.69	0.73	0.80	0.82
Model 8: Customer numbers/overhead/ underground	0.80	0.85	0.71	0.79	0.83	0.88
Model 9: Ratcheted max. demand/overhead/ underground	0.81	0.86	0.74	0.81	0.84	0.88
Average across specifications (non-reliability)	**0.79**	**0.83**	**0.70**	**0.76**	**0.82**	**0.86**

Source: CEPA analysis of Commerce Commission ID data.

Reliability

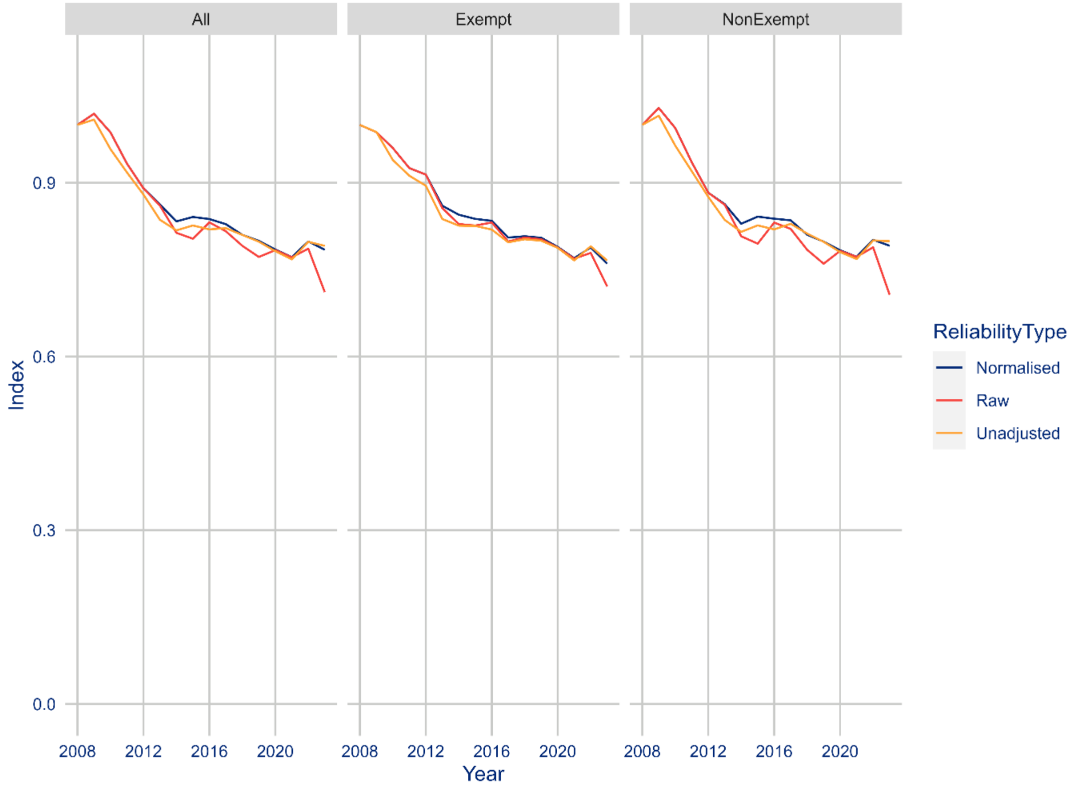
The figure below shows the TFP index for model 1 (connections and circuit length) and model 1 adjusted for our two measures of reliability. For clarity we present the average of the minimum and maximum TFP positions and do not show opex.

The figure below should be considered from the unadjusted model 1 (yellow line) position. We then adjust the productivity model for our two measures of reliability:

- Inclusion of raw minutes lost (red line) leads to a clear conclusion that adjusting for reliability leads to measured productivity falling quicker over period. There are however two distinct periods. Prior to 2013 the adjustment leads to slightly better productivity performance, albeit still falling. However, in between 2013 to 2023 measured productivity performance with the adjustment is generally worse with it being substantially worse in 2023.
- Inclusion of normalised minutes lost (blue line) leads to a less clear conclusion. In many years of the period an adjustment for normalised reliability improves measured productivity performance. Nonetheless, in 2023 the adjustment is downwards though not substantial.

We consider that when considering the productivity of EDBs it is important to include reliability. It is an important measure of the quality service customers receive from EDBs. However, the ultimate conclusions that are drawn from this finding depends heavily on attribution. It is possible to both conclude that service quality has fallen and by extension productivity of EDBs has fallen and conclude that this drop in service quality was outside the control of EDBs. This conclusion would be different than one where it is concluded that the drop in service quality should be attributed to EDB conduct. The use of normalised numbers may go part of the way in attributing falling reliability to external factors. Nonetheless, they do not support the finding that falling measured productivity can be offset by materially increased reliability.

Figure 14: TFP Index - Model 1 relative to model 5 (raw and normalised reliability)



Source: CEPA analysis of Commerce Commission ID data.

Time-varying cost of capital

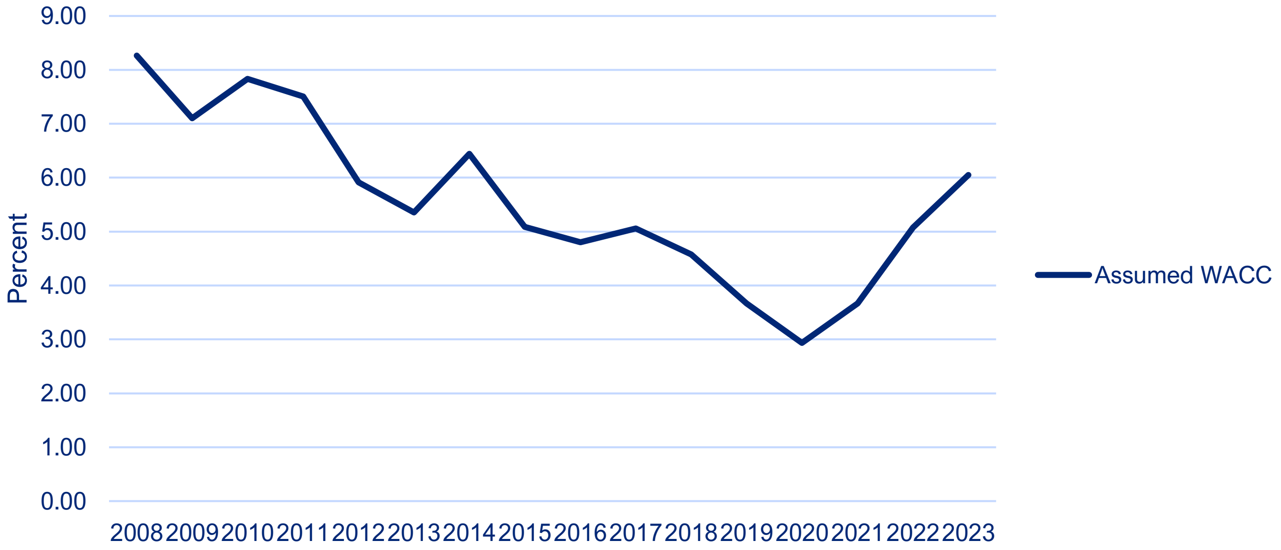
Cost of capital is a key assumption in the amortisation-based approach for setting the charge for capital services. In our results above we apply a static cost of capital of 5.6% for every year. However, the cost of capital, at least as estimated by the Commission for setting regulatory allowances, has not remained static over the period. Indeed, over the last five years the assumed mid-point post-tax WACC applied by the Commission to EDBs has varied from 3.52% to 6.05%.

It is possible to justify the use of a static cost of capital. If a time-varying cost of capital is applied, then conclusions around productivity may be driven by nothing more than changes in short-term financing conditions. These are not under the control of EDBs and EDBs may not be able to change their practices to take advantage of these changed conditions. As such, attributing falling or increasing productivity to these changes may not be informative.

Nonetheless, if capital costs materially change over time, we should expect some substitution between opex and capex for the delivery of services. For example, the long period of falling interest rates post-2008 may have led to EDBs using more capital relative to opex. If this was the case than the use of this 'cheaper' capital should be reflected in productivity measures. Failing to allow for a time-varying cost of capital implicitly assumes no such substitution is possible.

As a sensitivity we introduce a time-varying cost of capital. To create our time-varying cost of capital we use the 10-year New Zealand bond yield on 31st of March each year. To this we add a spread of 1.83% which is the difference between the 10-year bond yield on 31st March 2023 and the mid-point post-tax WACC as decided by the Commission for EDBs on 1 April 2023 of 6.05%.[33] The figure below shows the resulting time-varying cost of capital estimates.

Figure 15: Time-varying cost of capital



Source: CEPA analysis of Commerce Commission determinations and Eikon data

Switching to a time-varying cost of capital has a material impact on total cost as shown in the figure below. Total cost becomes almost completely determined by changes in short-term interest rates. Furthermore, as opex costs are unimpacted it also means that there is a substantial divergence between the trends in opex and total costs. The ending index position in 2023 is 22% higher than in 2008 compared to 42% with a static cost of capital. However, if

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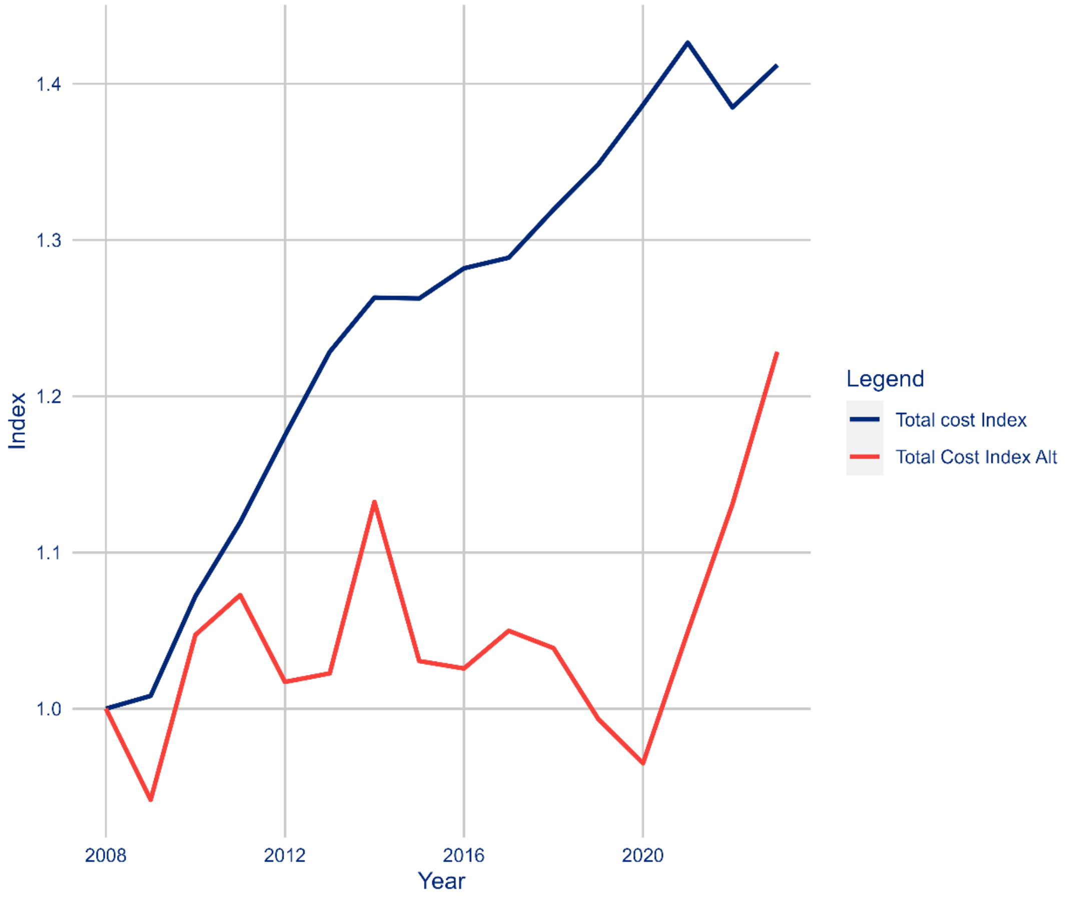
[33] There is a one-day discrepancy as the Commission calculated their WACC estimates on 1 April 2023 which was a Saturday and our financial data provider (Eikon) does not report a 10-year bond yield on that date.

interest rates were to continue to increase the gap would close. These features appear undesirable in the context of a productivity study.

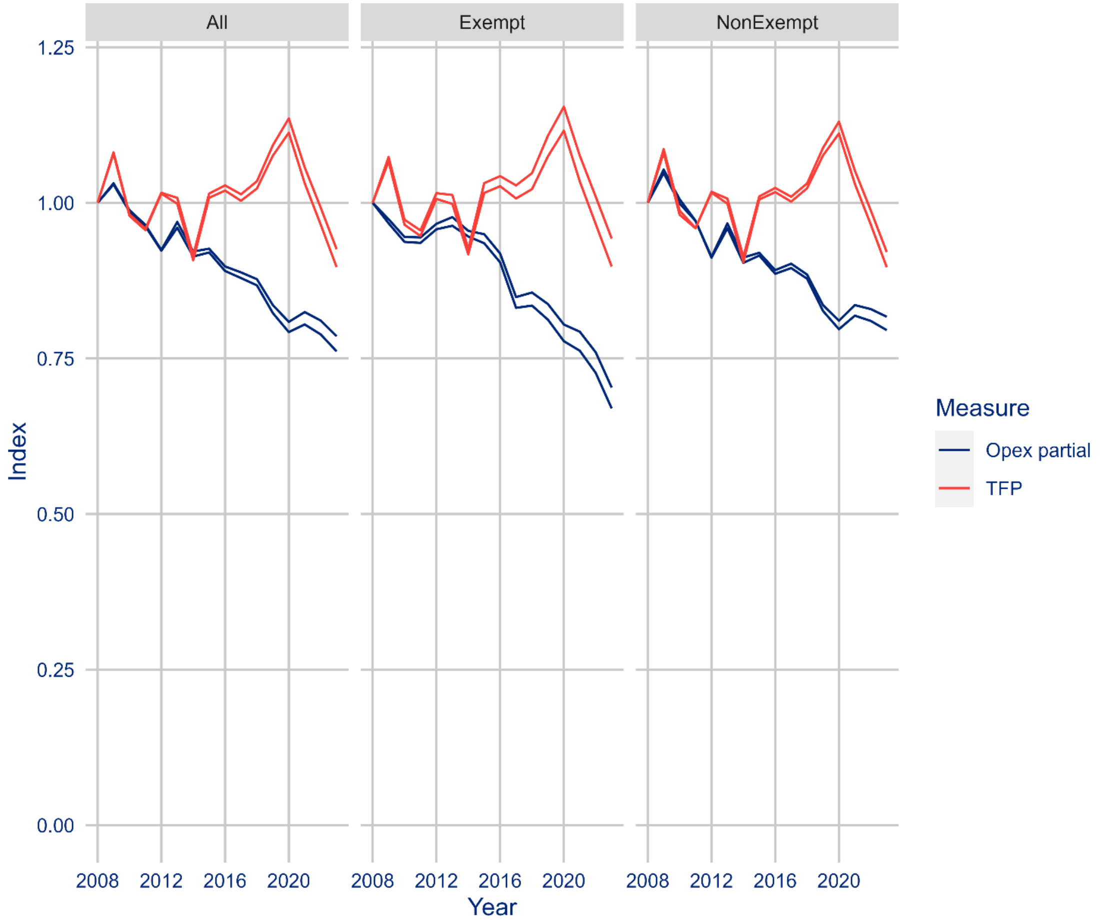
Figure 16: Comparison of input indexes – Static versus time-varying cost of capital



Source: CEPA analysis

The figure below shows the productivity index for model 1 using a time-varying cost of capital. Total factor productivity is still lower in 2023 than in 2008. However, if interest rates were to have remained at their 2020 level this model would show improving productivity.

Figure 17: Model 1 - Productivity indices with time varying cost of capital (Output: Circuit length/ICPs)



Source: CEPA analysis of Commerce Commission ID data.

5. RESULTS FROM ECONOMETRIC APPROACHES

We undertook econometric modelling of both total costs and operating costs using two functional forms, Cobb-Douglas and translog. We ran each model specification using both functional forms with and without EDB fixed effects (FE). The combination of these methods produces four different time trend estimations for each model specification, which are presented in this section, along with confidence intervals, for both total and operating expenditure. These four estimates are provided for the industry overall, exempt EDBs, and non-exempt EDBs.

5.1. OPEX

The tables in Section 5.4 contain the Cobb-Douglas model specifications we tested on both operating and total expenditure, presenting the time trend variable and whether the estimated coefficient was statistically significantly different from zero. The full set of regression results are presented in Appendix C.

All time trend variables are significant and positive. This is the case for both the fixed effects models and the models without fixed effects and the split between exempt and non-exempt EDBs.

The estimated time trends for the industry overall are between 1.2% and 2.2%. This means holding output constant an additional year leads to real opex rising by between 1.2% and 2.2%. It is important to note that it is only the factors that are included in the regressions that are assumed to be held constant. If there are any time-varying factors that are not accounted for than these will be captured in the time trend. The fixed effects specification should remove EDB specific factors but if there are trends across the industry that are driving costs than again these will be captured in the time trend.

It is interesting to consider the factors that appear to produce the lowest estimate of the time trend or in other words the lowest measure of ignorance. Splitting circuit length between overhead and underground capacity seems to have the largest impact on the estimated time trend. We understand that undergrounding is more expensive than running lines above ground. The cost estimates we produced for the output prices suggest it could be between twice and 8 times the cost of an overhead line on an annualized total cost MVA-km basis. However, the models seem to suggest that a cost differential is picked up in operational expenditure not just capital costs.

We find that the time trend for exempt EDBs is higher than non-exempt EDBs across all but one of the output specifications.[34] This aligns with our findings from the indexed-based methods where we found relatively higher growth in real opex for exempt EDBs even after accounting for faster output growth. For non-exempt EDBs the time trend is estimated to be between 0.8% and 2.2% which for exempt EDBs this is between 1.2% and 2.7%.

The use of the translog functional form does not seem to change the overall results by much. The significance and magnitude of the time trend variables are very similar. However, model 9 for non-exempt EDBs produces an insignificant time trend. The time trend switches back to significant when EDB dummies are introduced.

5.2. TOTAL EXPENDITURE

For the industry overall the time trends are significant and positive across all model specifications and regardless of whether fixed effects are introduced or not. The estimated time trends for total expenditure for the industry overall are between 0.9% and 1.7%. Generally, the time trends using total expenditure are lower than the time trends when we only include opex.

In terms of time trends, the split between exempt and non-exempt EDBs now goes in the opposite direction. The time trends for non-exempt EDBs generally sit higher than for exempt EDBs. This seems to suggest that exempt EDBs are economizing on capex relative to opex when compared to non-exempt EDBs.

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[34] At three decimal places model 8 produces identical estimates for exempt relative to non-exempt.

We also find that the time trend for model 9 for exempt EDBs is insignificant. However, significance of the time trend returns when fixed effects are included.

As with opex, the use of the translog functional form does not seem to materially change the overall results.

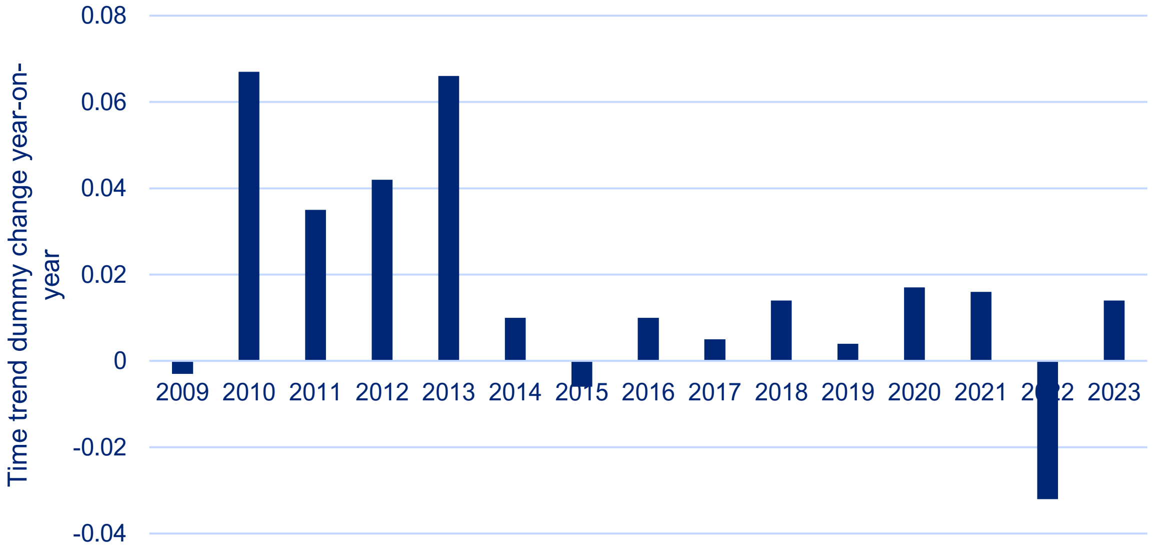
5.3. YEAR DUMMIES

In the econometric models described above we estimated a single parameter for time. This represents an estimate of the average change in costs when we advance one year forward holding the other parameters constant. It is possible to instead estimate the individual year impacts. We should see some consistency with our indexed-based methods where we found a fall to approximately 2014 before stabilising. The two figures below demonstrate that the econometric results are incredibly similar to the index-based methods. We use the model 1 output specification for these figures.

The first figure below shows the change in the econometric time trend estimate on a year-on-year basis. For example, the econometric time trend estimate from the model in 2012 was 0.216 suggesting that holding outputs constant costs in 2012 were 21.6% higher than the base year of 2008. To recover the year-on-year change we take the difference between the 2012 estimate (0.216) and the 2011 estimate (0.207). In this way we find that the year trend shows a substantial drop between 2010 and 2013.

The second figure attempts to show the econometric time trend estimates on a similar basis as the index-based methods. We set an index at 1 in 2008 and calculate all other positions as 1 minus the time trend dummy estimate in each year. This produces a trend over time which is very similar to that estimated using index-based method.

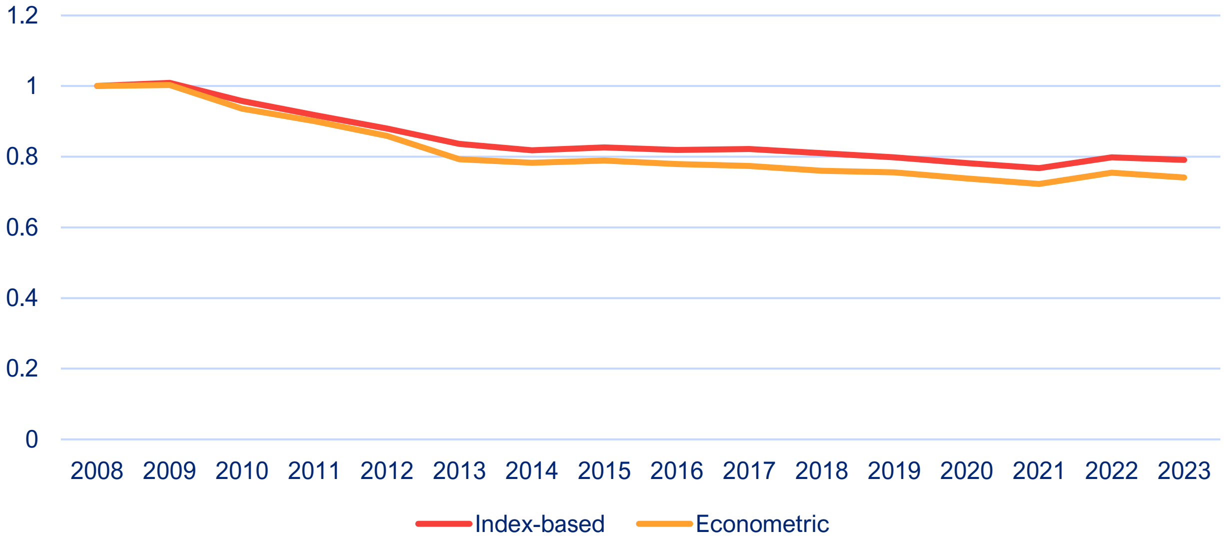
Figure 18: Time trend dummy estimates with year dummies – Model 1 – All EDBs - Year-on-year changes



Source: CEPA analysis of Commerce Commission ID data.

Note: The figure does not show the time trend dummy in each year but instead the change in the time trend dummy from the previous year.

Figure 19: Time trend dummy estimates compared to index-based – Total factor productivity - Model 1 – All EDBs



Source: CEPA analysis of Commerce Commission ID data.

5.4. ECONOMETRIC TIME TREND RESULTS

5.4.1. Cobb-Douglas - Operating Expenditure

Table 5.1: Time-Trend - All – Cobb-Douglas - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.022 ***	0.019 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.014 ***	0.017 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.022 ***	0.014 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.021 ***	0.013 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.019 ***	0.018 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.016 ***	0.014 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.020 ***	0.016 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.017 ***	0.017 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.011 ***	0.016 ***
Average across specifications (non-reliability)		0.018	0.016

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.2: Time Trend - Non-Exempt – Cobb-Douglas - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.020 ***	0.021 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.013 ***	0.015 **
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.020 ***	0.012 **
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.020 ***	0.011 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.022 **	0.022 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.015 ***	0.009
7	• Ratcheted Maximum Demand • Total Circuit Length	0.019 ***	0.014 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.014 ***	0.018 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.008 *	0.015 ***
Average across specifications (non-reliability)		0.016	0.014

***** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.

Source: CEPA analysis of Commerce Commission ID data.

Table 5.3: Time trend – Exempt – Cobb-Douglas - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.024 ***	0.017 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.024 ***	0.018 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.027 ***	0.016 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.023 ***	0.014 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.014 **	0.015 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.019 ***	0.016 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.022 ***	0.017 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.015 ***	0.019 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.012 ***	0.020 ***
Average across specifications (non-reliability)		0.021	0.017

*** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

5.4.2. Cobb-Douglas - Total Expenditure

Table 5.4: Time Trend – All – Cobb-Douglas - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.017 ***	0.020 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.009 ***	0.018 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.016 ***	0.016 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.016 ***	0.015 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.016 ***	0.019 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.013 ***	0.013 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.016 ***	0.015 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.012 ***	0.018 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.009 ***	0.015 ***
Average across specifications (non-reliability)		0.014	0.016

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.5: Time Trend - Non-Exempt - Cobb-Douglas - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.019 ***	0.023 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.011 **	0.020 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.018 ***	0.016 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.018 ***	0.015 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.020 **	0.024 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.016 ***	0.014 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.017 ***	0.016 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.016 ***	0.021 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.012 ***	0.017 ***
Average across specifications (non-reliability)		0.016	0.018

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.6: Time Trend - Exempt - Cobb-Douglas - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.016 ***	0.015 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.011 **	0.015 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.014 ***	0.014 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.015 ***	0.011 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.010 **	0.013 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.010 ***	0.010 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.013 ***	0.011 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.005 *	0.007 **
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.004*	0.006 *
Average across specifications (non-reliability)		0.011	0.011

***** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

5.5. TRANSLOG

5.5.1. Translog - Operating Expenditure

Table 5.7: Time-Trend - All – Translog - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.022 ***	0.019 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.012 ***	0.019 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.024 ***	0.020 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.021 ***	0.016 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.019 ***	0.019 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.018 ***	0.016 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.020 ***	0.018 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.015 ***	0.017 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.010 ***	0.018 ***
Average across specifications (non-reliability)		0.018	0.018

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.8: Time Trend - Non-Exempt - Translog - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.020 ***	0.022 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.017 ***	0.014 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.023 ***	0.019 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.019 ***	0.015 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.022 ***	0.026 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.014 ***	0.013 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.019 ***	0.018 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.013 ***	0.017 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.004	0.016 ***
Average across specifications (non-reliability)		0.016	0.017

***** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.9: Time Trend – Exempt - Translog - Operating Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.024 ***	0.018 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.023 ***	0.020 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.028 ***	0.019 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.025 ***	0.015 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.018 ***	0.012 *
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.022 ***	0.014 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.022 ***	0.017 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.016 ***	0.017 **
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.010 **	0.021 ***
Average across specifications (non-reliability)		0.021	0.018

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

5.5.2. Translog - Total Expenditure

Table 5.10: Time Trend – All - Translog - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.018 ***	0.020 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.008 **	0.019 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.019 ***	0.020 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.017 ***	0.016 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.015 ***	0.018 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.014 ***	0.013 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.016 ***	0.015 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.009 ***	0.015 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.007 ***	0.013 ***
Average across specifications (non-reliability)		0.014	0.016

***** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.11: Time Trend - Non-Exempt - Translog - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.019 ***	0.023 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.017 ***	0.020 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.020 ***	0.025 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.018 ***	0.017 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.021 ***	0.025 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.015 ***	0.015 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.018 ***	0.017 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.010 ***	0.020 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.006 *	0.016 ***
Average across specifications (non-reliability)		0.015	0.019

**** Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

Table 5.12: Time Trend – Exempt - Translog - Total Expenditure

Model number	Outputs	Time trend	Time trend (FE)
1	• Number of Connections • Total Circuit Length	0.016 ***	0.017 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.007	0.018 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.017 ***	0.017 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.014 ***	0.014 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.012 ***	0.014 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.011 ***	0.009 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.013 ***	0.010 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.005 **	0.012 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.002	0.008 ***
Average across specifications (non-reliability)		0.011	0.013

***** *Significant at <0.1%, ** Significant at < 1%, * Significant at < 5%.*

Source: CEPA analysis of Commerce Commission ID data.

6. DISCUSSION AND CONCLUSIONS

In all of our models the productivity index declined over the period 2008-2023. According to both the index-based and econometric methods, there is a rapid decline in the productivity indices over the first part of the period (2008-2014) and a slower decline in productivity indices in the latter part of the period.

In this section we consider why our productivity index measure may not adequately capture productivity changes. This includes considering some of the reasons raised by stakeholders on our draft report. We also compare our productivity measures with Stats NZ's numbers.

6.1. POTENTIAL EXPLANATIONS

Whilst the results, at an EDB level, suggests that both operational and total costs have increased at a higher rate than corresponding outputs, this may not automatically provide conclusive evidence that productivity has declined, and it may be that:

- We have not captured all of the changes in the output of EDBs for example:
    - EDBs have changed their output in various ways that are not captured in this study. For example, EDBs may have changed their work practices, resulting in fewer workplace injuries or deaths. This is a social benefit that is not being captured here. Another possibility is that EDBs have significantly improved their resilience to cyber attacks. Again, the value of this investment in cyber security is not captured here. This is discussed further below.
    - EDBs are focusing on customer-service or quality dimensions which are not picked up in this study, such as providing more timely information to consumers, better websites, or faster telephone response times. To the extent that these services are valued by consumers, these would not be captured in this study.
    - EDBs are providing new services as part of the energy sector transition, which are not captured here. The service provided by EDBs is changing as climate change-related demand and decarbonisation-related activities (e.g., electric vehicles, solar panels) increase. As highlighted in Section 2.3, EDBs are evolving over time into distribution system operators and distribution market operators. These new services would not be picked up in this study.
- There is a change in the operating environment which is affecting the output of EDBs which is not being fully taken into account in the input and output measures.

  There could be other, external factors, which are driving a change in the costs for a given level of output. For example, it may be that unusual weather patterns resulted in an increase in operating expenditure required to achieve a given level of reliability over this period. In addition, there could be increased regulatory obligations, such as financial reporting and disclosure requirements, or increased obligations to protect against cyber-security threats.
- Capital costs are not being handled correctly. For example:

  In the event that, say, EDBs decided to switch from capex to opex, this would be reflected in an immediate increase in opex, whereas the reduction in capital costs may take time to flow through to the regulatory asset base. This might appear as a decline in productivity in the short and medium term.

  Our measure of capital costs assumes a fixed cost of capital over the period. This is consistent with a view that the capital stock can only change slowly in response to a change in the relative price of capital and labour. In fact the cost of capital declined over the period. If EDBs are, in practice, able to increase their capital stock in response to this change in prices this would not be fully picked up in our methodology.
- Prices used to value outputs are incorrect, or out-of-date at the end of the period.

  It may be that with prices calculated in a different way (perhaps on a smaller, more recent sample) results in different productivity measures. Alternatively, it may be that the use of cost-based prices yields results which do not fairly reflect the value (or the relative weighting) that consumers place on these services.

- Price deflators used to adjust outputs or inputs are not appropriate for EDBs. For example:

  It may be that EDBs are subject to large increases in input costs which are not reflected in the general input cost deflator. For example, EDBs may be larger-than-average purchasers of insurance. The increase in insurance premiums following the Christchurch and Kaikoura earthquakes may have increased input costs more than other businesses, for reasons that are outside the control of the EDBs.
  This point is emphasised in many of the submissions. For example, Vector writes:
  “insurance premiums are increasing at an alarming rate across the globe but in our sector in particular given the effects of climate change and natural disasters on infrastructure. ... In 2023 insurance costs were 70% higher than they were in 2016. A trend which is not unique to Vector.”

6.2. OPERATING EXPENDITURE

Productivity, in the context of increases in operating expenditure, is an area the Commission have received feedback on from the EDB industry in recent years. In May 2022, the Commerce Commission published a ‘Process and Issues’ paper related to the ‘Part 4 Input Methodologies Review 2023’. The aim of the paper was to seek stakeholder input, including EDBs, in identifying key topics and specific problems to be address in the review of the input methodologies[35]. Within this paper, the Commission highlighted that expenditure by EDBs had increased significantly since 2008, nearly doubling in nominal terms, whilst average operating expenditure productivity appeared to have steadily declined since 2002. More recently, in November 2023, the Commerce Commission published the ‘Default price-quality paths for electricity distribution businesses from 1 April 2025’ issues paper, which included requests for stakeholder feedback across a range of areas, including forecasting operating expenditure and setting revenue allowances.

Overall, responses to these papers from the EDB industry, in relation to operating expenditure, have attributed the perception of declining productivity to the operating environment becoming increasingly complex and costly, alongside requirements on the electricity sector to support the climate ambitions of New Zealand. There was the suggestion that many of the factors impacting upon EDB costs and productivity are extrinsic and difficult to control and/or influence, and the productivity measures currently utilised omit consideration of how these impact the delivery of services (e.g., quality, safety, legislative/regulatory compliance). Whilst expenditure in these areas is considered not to improve the productivity metrics measured by the Commission, respondents noted these provide essential services for both the current and future network. The drivers typically used, such as network lengths, energy delivered, and ratcheted maximum demand, do not fully reflect the increased expenditure of EDBs, particularly on non-network opex and fail to reflect a number of activities which are now part of being an EDB.

More specifically, there were a number of common factors highlighted in the EDB responses, related to increased operational, regulatory, and business complexity, attributed to having influenced productivity which included:

- The introduction of the **Health and Safety at Work Act 2015 (HSWA)** has required operational changes, for which it has taken time for the EBDs to understand and adapt to and been attributed to increased costs that have no associated productivity benefit. This has included a reduction of the use of live line working, leading to more frequent and prolonged planned outages, as well as significant changes to traffic management practices. The latter are now more complex, requiring increased staff and equipment to implement, and accounting for a higher proportion of total costs. It was noted by one respondent that whilst there has been an enhancement in worker safety, as a result of the HSWA, this has not delivered more kWh or served more customers.

- The introduction of the **Heritage New Zealand Pouhere Taonga Act 2014**, was identified as causing significant operational and financial burden, with no associated output or productivity increases.

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[35] Input methodologies are the upfront rules, processes, and requirements of regulation, set for services that are regulated under Part 4 of the Commerce Act, namely electricity networks, gas networks, and airports. The Commerce Commission are required to review the input methodologies at least every seven years.

- **Severe weather events**, which are increasing in frequency due to climate change.
- The **cost of insurance** has increased significantly, particularly following the Christchurch and Kaikoura earthquakes. Respondents noted that insurance cost increases within the DPP3 period, are expected to continue across DPP4, attributed to the rising costs and frequency of extreme weather events, in both New Zealand and globally, resulting in increased premiums. The increase in insurance costs has not resulted in a corresponding increase in the output drivers used to measure productivity.
- Increased **investments in cyber-security**, due to a growing reliance on digital technologies and the digitisation of network management alongside rising threat levels, in turn increase the cost of IT inputs. This is considered to be largely not controllable by the EDBs, with services typically provided by a third-part supplier.
- The growing **investment by customers in energy efficient technologies, generators, and batteries** has resulted in less kWh being delivered over the same lines, reducing energy throughput whilst not reducing network costs, as well as requiring the introduction of new services (i.e., allowing customers to use the network and realise the value from their generation).
- The **impact of COVID-19**, which resulted in a period of higher rates of absenteeism due to isolation requirements.

We have further examined EDB operational expenditure data across an 11-year period, from 2013 to 2023[36], at a total industry level. This has been undertaken on a proportional basis, due to EDB reservations around factors driving cost increases not being associated with currently measured outputs.

Table 6.1: Operating expenditure cost disaggregation available in EDB information disclosure

Level 1	Level 2	Level 3
Operational Expenditure	Network	Asset replacement and renewal
		Vegetation management
		Routine and corrective maintenance and inspection
		Service interruptions and emergencies
	Non-Network	System operations and network support
		Business support

The EDB sector has maintained a consistent split of ~40% network and ~60% non-network opex, as illustrated in the figure 20 below. This suggests that, as operating expenditure has increased, both network and non-network expenditure have grown at broadly equal rates (i.e., neither have driven the increase in opex).

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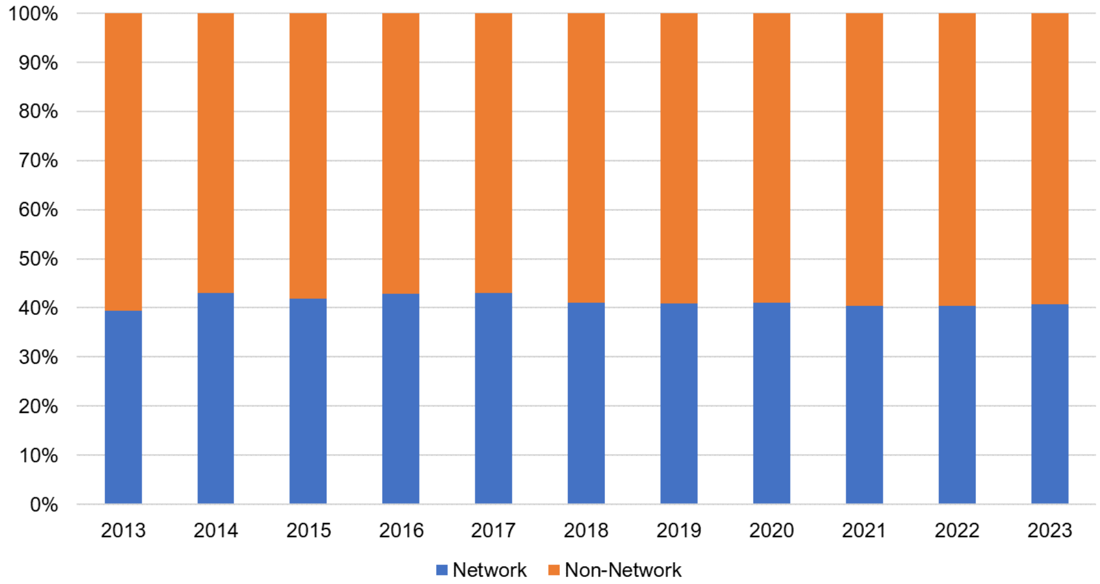
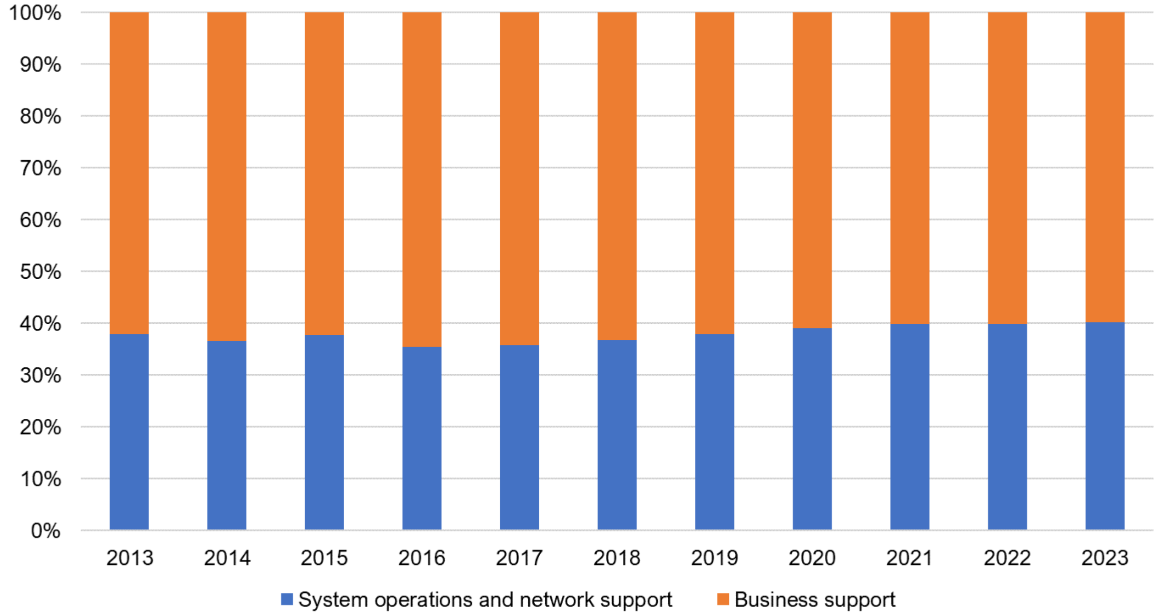
[36] This time period has been used as the disaggregation of opex currently reported by the EDBs is not available pre-2013

Figure 20: Network and non-network expenditure as a proportion of operating expenditure across all EDBs



The components of non-network opex have also maintained a fairly consistent split of ~40% system operations and support and ~60% business support, as illustrated in the figure below. System operations and network support has increased at a slightly higher rate than business support, and its proportion of non-network opex has increased marginally from 2013 to 2023. This suggests it may have driven the increase in non-network opex more so than business support, but neither cost area have growth a rate that appears overly out of alignment with the overall rate of growth in non-network opex.

Figure 21: Proportions of non-network operational expenditure across all EDBs



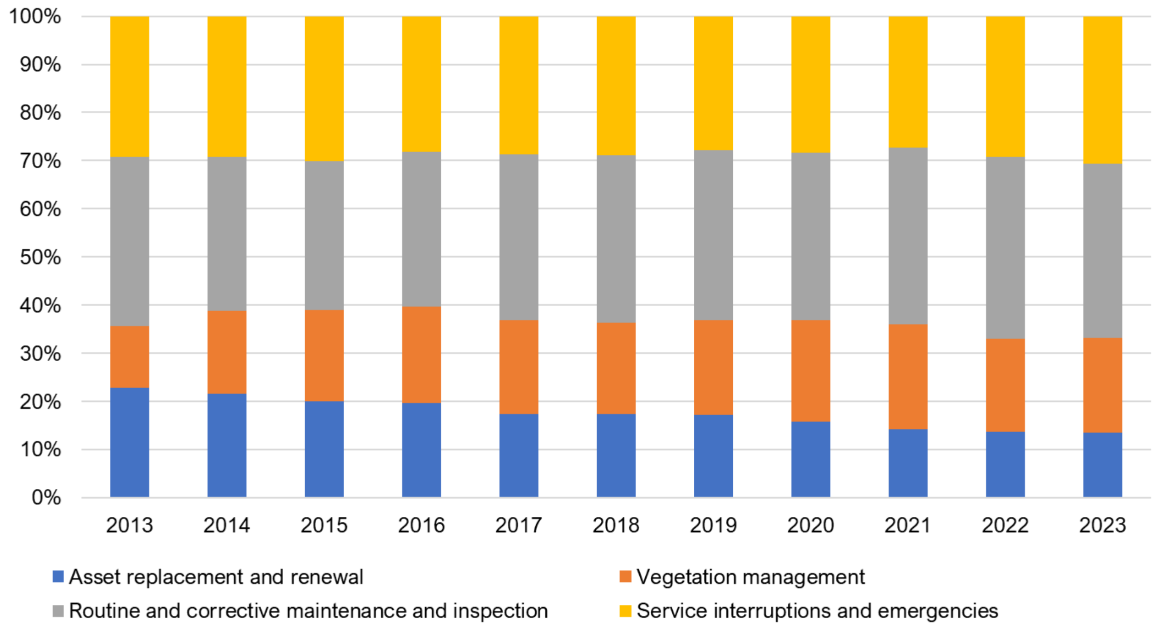
Regarding the components of network opex:

- **Service interruptions and emergencies** has consistently accounted for ~30% across the period.
- **Routine and corrective maintenance** has consistently accounted for ~35% across the period.
- **Asset replacement and renewals** has seen a gradual reduction in the amount it of network opex it accounts for, declining from 23% to 13%. The vast majority of networks appear to be spending less

operationally on asset replacements and renewals in 2023 than in 2013, although we note that capital expenditure on asset replacements and renewals has increased across the same period.

- **Vegetation management** has increased from 13% to 20% across the same period. This increase, however, occurred between 2013 and 2014, as a number of networks either did not incur or record expenditure in this category until 2014, after which the proportion remained around 20%.

Figure 22: Average proportions of network opex across all EDBs



Whilst expenditure on asset replacements and renewals has declined across the period, the other three cost areas have not consistently or notably increased across the previous decade in order to identify any specific driver of the increase in network opex.

The EDB sector considers that the outputs used historically to measure productivity across the industry no longer fully reflect the operating environment, due to material changes and new areas of expenditure are being incurred in areas that do not improve the current outputs considered by the Commission when analysing productivity. (e.g., the EDBs are spending more per km of circuit or connection due to meeting needs not directly related to the scale of the network). We understand that the environment an EDB operates in may change over time and that the electricity sector is currently in a period of transition outside of EDB control and the future may be different to the past and present.

However, at an industry level, given the breakdown of operating expenditure in the information disclosures, it is not clear that there is a particular category of operating costs that has increased more than other categories. This could suggest that the EDB industry has experienced a general decline in operating productivity, the changing environment in which EDBs operate has resulted in increases in operating expenditure across the board, or the drivers of the cost increases are not included as an output in our productivity indices.

6.3. PRODUCTIVITY COMPARISONS

In their submission the ENA highlight that it is useful to consider the productivity estimates in the context of broader New Zealand productivity trends.[37] Aurora also draw attention to other recent work on productivity.[38]

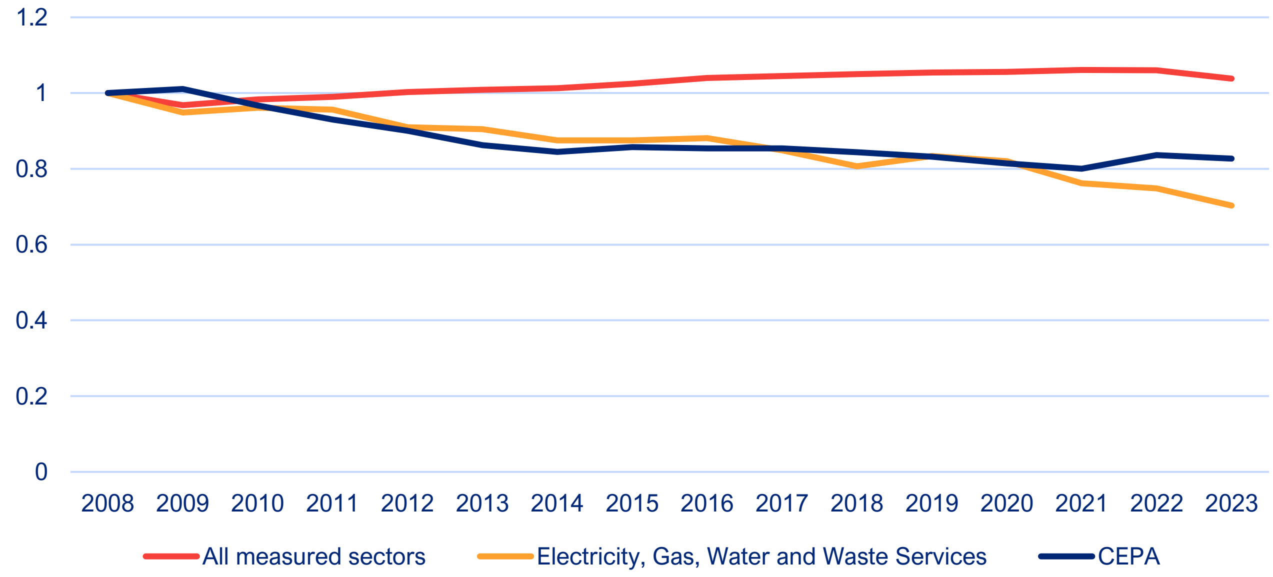
We agree. Understanding whether these trends are specific to the EDB sector or broad-based allows us to start to consider whether the drivers of productivity decline are sector specific and what might need to change for measured productivity to begin to increase. A thorough examination of these issues is beyond the scope of this report. Nonetheless, we make a few observations.

The ENA draw a comparison to Stats NZ's estimates of productivity for the 'Electricity, Gas, Water and Waste Services' sector. Stats NZ reports productivity for this sector jointly and does not provide a disaggregation. We reproduce the equivalent of ENA's figure below and add their estimate for productivity measure for all measured sectors.

New Zealand wide productivity growth, as represented by Stats NZ's all 'measured sectors category', has increased slowly since 2008. This is not the case for our estimates of EDB sector productivity or Stats NZ's estimates of the wider electricity, gas, water, and waste services sector. We observe that our estimates of productivity align very closely with Stats NZ. Drawing a comparison to the gas and water sectors appears appropriate due to their networked nature and similarly high capital intensity. However, it is not clear whether the comparison to waste services is as apt. Unfortunately, Stats NZ does not provide a further breakdown.

If productivity trends are being driven by the same factors in the gas and water sectors as for electricity distribution then this may suggest a different set of policies for improving productivity than if the decline were restricted to EDBs alone.

Figure 23: Comparison to Stats NZ productivity estimates



Source: CEPA analysis of Stats NZ data.

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[37] ENA (2024), Submission to the Commerce Commission on CEPA EDB Productivity Study.

[38] Aurora (2024), Feedback – EDB Productivity Study.

6.4. MISSING OUTPUTS AND OPERATING ENVIRONMENT FACTORS

One of the key reasons why a productivity study may yield misleading results is if that study fails to include all the relevant outputs and factors which affect the costs of the regulated firms. Many of the submissions to the draft report highlighted possible missing outputs. If an EDB is incurring costs to provide an output and this output is not captured in the output specification, then this will appear as reduced measured productivity. Similarly, if there are other environmental factors which affect the costs of the EDBs, and those factors are not directly measured and are getting worse over the period, this would show up as reduced measured productivity.

In this section we discuss possible omitted output variables and operating environment factors. We then discuss how the inclusion of new outputs might shift our findings on productivity. We do this in reference to two specific suggestions on health and safety and DER.

Missing outputs

In principle, *any service* that EDBs provide that is actively desired by their customers is a candidate to be included as an output in a productivity study. However, there are certain key difficulties which must be addressed before we can include a given output in a productivity study:

- First, in a sector-wide study such as this, questions arise if the customers of different EDBs desire different outputs (e.g., if one set of customers desire lower carbon emissions, and another set desire more undergrounding) -- in this case aggregating the different outputs to assess sector-wide productivity is difficult.
- Second, it must be possible to quantify the quality and quantity of the service provided. That is, we must be able to obtain numerical data on the volume of services offered in the relevant period (typically annually) and as well as information on how much customers value those services. Ideally, this information would be provided over the full time period (2008-2023, annually) and broken down by the categories of firms (e.g., Exempt, Non-exempt)
- Third, the output measure should not duplicate other measures (for example, there may be an overlap between measures of `customer satisfaction’ and measures of `value for money’ if those were selected).
- Fourth, the output measure must be capable of being monitored or measured on a timescale relevant for the productivity analysis (as discussed below).

Some measures of output (such as resilience to natural disasters, extreme weather, cyber-security attacks, or bushfires) may be difficult to measure directly. It is difficult to quantify the degree of resilience to, say, a cyber-security attack in any one year. It may be possible to observe how well a network responded when a natural disaster occurs, but if those natural disasters occur infrequently these observations will not be frequent enough to include in an annual productivity analysis.

One possible response is to use *proxies* for this resilience, such as the annual expenditure on network hardening, on vegetation management, or on network monitoring and controls. A key problem with the use of proxies is that it is difficult to verify that the expenditure involved is efficient or leads to the desired outcome (greater resilience). In addition, some expenditure on network hardening may have effects which last over time, giving it the characteristic of capex, giving rise to a cost allocation problem.

One of the key issues with missing outputs is that they are unmeasured. In their submission, NERA implicitly assume that unmeasured outputs have increased and by extension that EDBs are required to have become more productive over the period where measured productivity was stable.[39] However, as the outputs are unmeasured it is

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[39] NERA (2024), Implications of CEPA’s draft findings for the NZCC’s decisions on opex productivity for DPP4.

difficult to attribute directionality. Furthermore, it remains entirely possible that there are another set of unmeasured outputs that have decreased over the period.

Missing operating environment factors

In many cases the input required to deliver a given level of output depends on some external factors outside the control of the regulated firm. The weather is one such factor. Extreme weather events may result in substantially higher levels of opex for a given level of reliability, or may result in a fall in reliability even though the overall "level of service" of the EDB remains the same.

Certain regulatory obligations may also fall into this category, such as financial reporting or disclosure obligations. In principle those regulatory obligations will deliver some benefit to society as a whole (otherwise they wouldn't be implemented). Complying with these regulatory obligations could be viewed as an *output*. In some cases it will be possible to quantify the services to society from complying with the obligation (e.g., reduced worker deaths or injuries, or reduced traffic accidents), but this will not always be the case. In this case it is easier to view the regulatory obligation as part of the operating environment factors – which are not necessarily directly desired outputs by customers.

Again, problems can arise in quantifying these factors. Even in the case of weather events, where weather statistics are available, the effects of weather may be very local – making network-wide assessments difficult. As just noted, for many regulatory obligations, such as financial reporting requirements, it is difficult to quantify the output provided. We may instead use proxies, such as expenditure required to meet regulatory obligations, but again this suffers from the drawbacks that it is difficult to assess efficiency of such expenditure or to attribute expenditure to the obligations.

In principle, operating environment factors can be distinguished from outputs in that customers do not directly desire the operating environment factors. But this distinction is somewhat subtle. We could view the impact of weather as another output ("weather-related-network-repairs") which customers value and which varies exogenously with the weather. Fortunately, it is not necessary to draw a strong distinction between outputs and operating environment factors. The submissions to the draft report do not draw a strong distinction. We have included both in the table below.

Table 6.2: Summary of possible outputs suggested in submissions and short commentary

Category	Output or OEF	Comment
Possible outputs	Reduced carbon emissions Increased customer engagement	These services are likely to be valued by customers and therefore are candidates for outputs. Quantifying customer engagement may be tricky.
Regulatory obligations	Increased regulatory and financial disclosure/ reporting obligations	Regulatory obligations can be treated as OEFs. It is likely to be difficult to quantify the output provided. It may be necessary to use proxies.
Indirect outputs	Worker health and safety Traffic management	These may be regulatory obligations, in which case they could be treated as OEFs. Data may be available which could be included in productivity analysis (as set out below for worker health and safety).
Resilience measures	Resilience to extreme weather Resilience to cyber-security attacks Vegetation management	It is likely to be difficult to directly measure the degree of resilience for any given level of expenditure. Proxies may be required.

Category	Output or OEF	Comment
	Increasing automation and maintenance procedures to improve reliability	
New products, services	Increased complexity of new connections Increased costs associated with DER integration New products, services	All products and services should in principle be included in the output measures. Quantifying bespoke services is difficult. Consideration could be given to measuring these services and including them in productivity analysis.

Handling of insurance

Some submissions (e.g., Vector, NERA) suggested the inclusion of "insurance" as an additional output. We understand that the driver for this is that the cost of insurance has risen rapidly, faster than the price of other key inputs, and this could be a driver of the apparent decline in productivity.

We accept that, by bundling insurance with the other categories of inputs, if the price of insurance has risen rapidly, it is possible that the input price inflation faced by EDBs may be different from the input price deflator used in our model. This may result in the appearance of a productivity decline.

While we do not view insurance as an "output", it is possible that separating out insurance as a separate category of input, with its own price, may mitigate the effect of insurance price changes on the productivity estimates. This would require additional data. If insurance continues to be a major driver of input costs, we recommend that the Commission consider collecting data on insurance prices for future productivity studies.

Impact of proposed new outputs

There are two proposed outputs where with some data transformation the requirements for inclusion can be met. These are health and safety and integrating distributed energy resources (DER), which we discuss in turn below.

Health and safety

The ENA provides evidence that health and safety in the electricity distribution sector has improved since 2009.[40] We consider that health and safety is a valid output and something that EDBs will incur costs in producing. In this sub-section we consider health and safety through the lens of an output, rather than say an operating environment factor. It is possible that health and safety requirements lead to costs greater than that attributable to increased outputs.

The ENA provides a chart on Lost Time Injury Frequency Rate (LTIFR) from data compiled by the Electricity Engineers Association. There are, however, some issues with converting the data in the chart so that it is usable in a productivity index. We extracted the data from the chart (as it is not publicly available elsewhere) and make the following assumptions:

- The 2008 position is the same as the 2009 reported position on the chart (2.71). We extract the figures for the other years from the chart.
- The reported LTIFR is the injury rate per 200,000 hours worked. This means at the start of the period EDBs lost 2.71 hours per 200,000 hours worked. To introduce this as an output we need to assign a price and it does not seem natural to consider a price on a rate per 200,000 hours worked. It seems more natural to consider total hours lost. We have attempted to convert the rate to hours lost:

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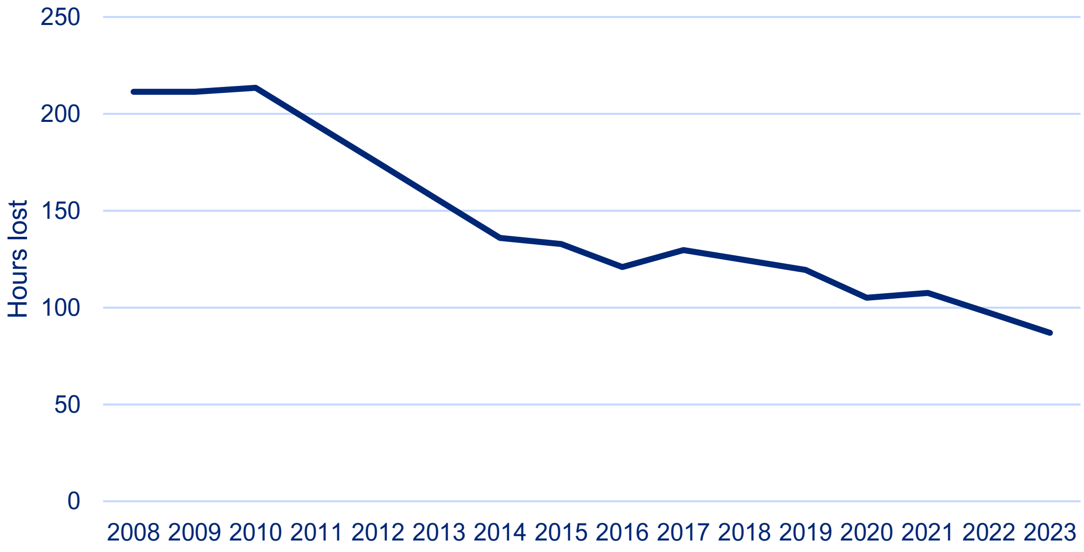
[40] ENA (2024), Submission to the Commerce Commission on CEPA EDB Productivity Study.

  - The EDB sector employs 10,000 employees.[41] We assume that this means that total EDB hours worked per year is 15,600,000 (30*52*10,000). We acknowledge this is an inexact estimate and the total number of employees varies over the period.
  - Using an assumption of 15,600,000 total hours worked per year means an LTIFR of 2.71 converts to 211 hours lost.

The figure below shows total hours lost to injury in the EDB sector under these assumptions.

Figure 24: Estimate of hours lost per year to injury in EDB sector



Source: CEPA analysis of data provided by ENA

We then need to assign a price per hour lost to injury. In the context of roads, New Zealand based assumptions on the value of fatalities and injuries are available.[42] These are shown in the table below.

Table 6.3: Assumptions for value of injuries in New Zealand

Type	Value
Fatality	$12,500,000
Serious injury	$660,100
Minor injury	$68,000

Source: NZIER (2023)

We need to convert these values into equivalent hours lost. The Australian 1990 'Workplace Injury and Disease Recording Standard' treats a fatality as 220 work days lost for lost injury time reporting purposes.[43] We have been unable to identify whether an equivalent New Zealand standard exists or whether the Australian standard has since been updated. Using this equivalence suggests that $12,500,000 converts to $7,575 per hour. As lost time due to injury is a dis-benefit and this would be introduced into the productivity model as negative $7,575 per hour.

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[41] ENA (2023), Electricity Networks Aotearoa Briefing to Incoming Energy Minister.

[42] NZIER (2023), The value of safety improvements, which references Waka Kotahi NZ Transport Agency.

[43] Australian Standard (1990), Workplace injury and disease recording standards.

We find that introducing lost time due to injury at a price of -$7,575 per hour has a negligible impact on productivity estimates. Using our model 1, the ending position of the TFP index in 2023 is 0.7931 without accounting for lost injury hours compared 0.7939 if this is included. As the reduction in hours lost is substantial in relative terms (i.e. a reduction of over 50% over the period) it is possible for this to materially reduce the measured productivity decline. However, to do so appears to require placing an unrealistically high price on this output.

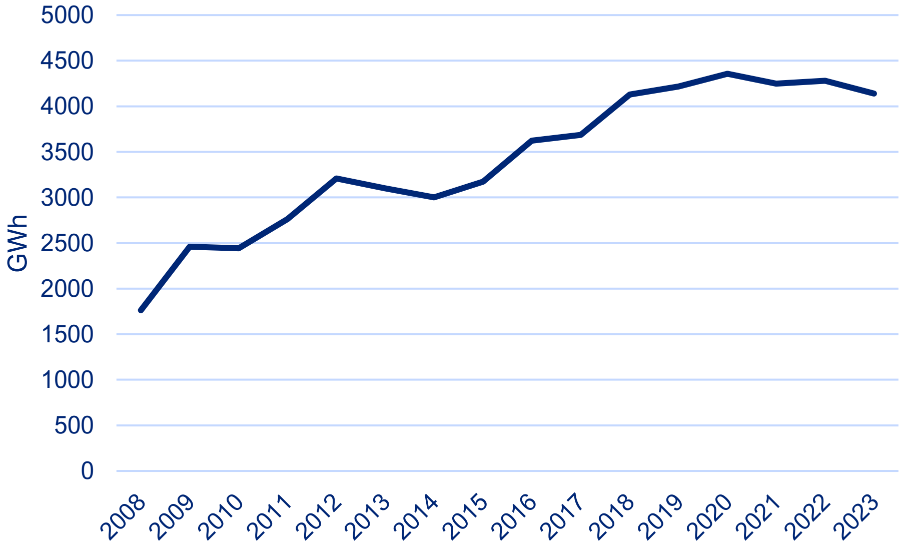
Integrating DER

Several stakeholders pointed to integrating DER or similar services as a growing output.[44] We acknowledge that the role of distribution networks is changing. Allowing customers to connect and export electricity is a valuable service. To incorporate this output into our productive measures we need to identify an output quantity and then place a price on this.

The ID dataset provides some options for incorporating this output. These include electricity supplied from distributed generation, number of distributed generation connections made per year and capacity of distributed generation installed in a year. Unfortunately, only electricity supplied is available in the older 2008 to 2012 dataset. To create a measure for the entire time period, we propose to use electricity supplied by distributed generation as our output measure.

The figure below shows that there has been substantial growth in electricity supplied by distributed generation since 2008. Electricity supplied by distributed generation is 2.3 times higher in 2023 than in 2008.

Figure 25: Electricity supplied by distributed generation



Source: CEPA analysis of Commerce Commission ID data.

To place a weight on this output in our output index we must assign a price. We previously estimated cost-based prices for energy delivered as a potential output (Section 4.2.1). We could place the same price on flows in the other direction, namely an output price of between $13,000 and $16,000 per GWh. While we have not tested an econometric cost approach to recover an output price for DER, we think it unlikely that this would produce such a high price. EDB costs are unlikely to be driven by DER penetration to such a substantial extent. Nonetheless, there is some logic to using the same output price as this implies customers place the same value on imports and exports. For simplicity we apply a price of $14,500 per GWh.

The figure below demonstrates that the inclusion of DER at this price has a material impact on measured productivity. Our model 1 produces a TFP trend of approximately -1.5% which reduces to approximately -1.4% with

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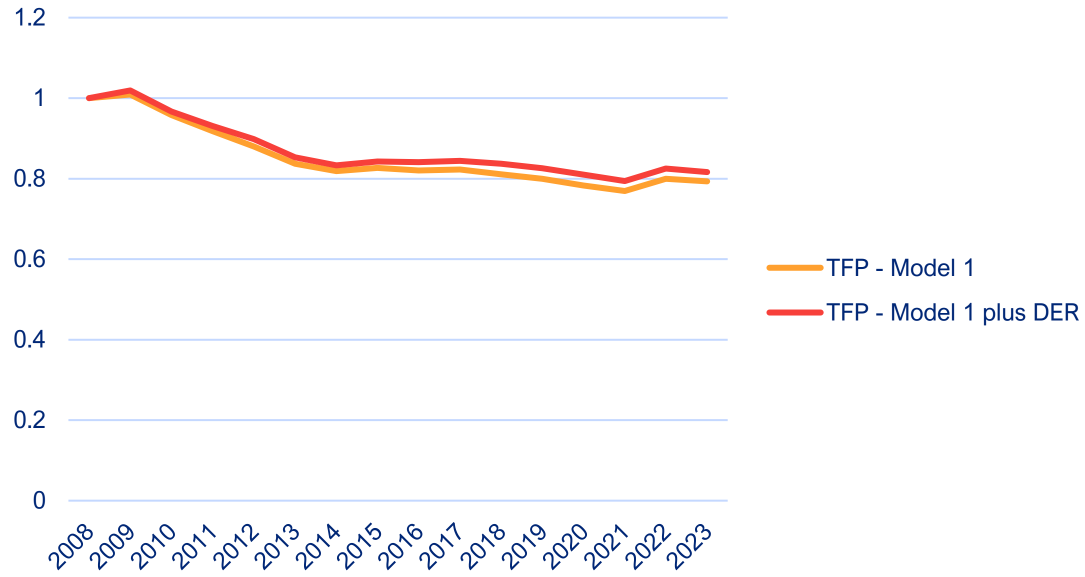
[44] Stakeholders used varied language for a similar output, for example “DER penetration”, “LV management”, “capacity of distributed generation”, “integrating DER”, “connecting DER” etc.

the inclusion of DER. Some of the decline in measured productivity is offset as EDBs are now providing more services that allow exports from DER.

Figure 26: Comparison of TFP trends Model 1 with and without DER



Source: CEPA analysis

Appendix A DATA DESCRIPTION

We extracted data from the information disclosure datasets as published on the Commission's website to undertake our analysis. The table below shows the data items that were extracted.

Data item	Field 2008-2012 dataset	Field 2013-2023 datasets
Operational expenditure	Total operational expenditure	Operational expenditure
Total asset value	Regulatory value of System Fixed Assets at Year End	Total Closing RAB value
Transformer capacity	Total distribution transformer capacity	Total distribution transformer capacity
Overground	Circuit Length by Operating Line Voltage (at year end) – Overhead	Circuit length by operating voltage (at year end) – Overhead (km)
Underground	Circuit Length by Operating Line Voltage (at year end) – Underground	Circuit length by operating voltage (at year end) – Underground (km)
Connections	Number of Connection Points (ICPs) at year end	Average no. of ICPS in disclosure year
Demand	Maximum System Demand	Maximum coincident system demand
Energy delivered	Electricity Supplied to Customers' Connection Points	Total energy delivered to ICPs
Circuit length	Total circuit length (for Supply)	Total circuit length (for supply)
Reliability	Reliability by interruption class - Class B Reliability by interruption class - Class C	Class B (planned interruptions on the network) Class C (unplanned interruptions on the network)

Appendix B ECONOMETRIC ESTIMATION APPROACH

Firms produce outputs using inputs according to a production function given by $Y = F(K, L, M)$. Assuming that firms face competitive factor markets (i.e., labour, capital, and intermediate good markets), they will optimise their choice of inputs to produce a given level of output based on factor prices and marginal products. That is, the demand for a given input (say labour) can be written as $L^* = L^*(Y, P_L, P_K, P_M)$. Thus, the firm's objective can be written as a cost minimisation problem subject to the constraint of their production function:

$$\Lambda = \min_{K,L,M} P_K K + P_L L + P_M M + \lambda(Y - F(K, L, M))$$

The first order conditions are

$$\frac{\delta\Lambda}{\delta K} = P_K - \lambda F_K(K, L, M) = 0$$

$$\frac{\delta\Lambda}{\delta L} = P_L - \lambda F_L(K, L, M) = 0$$

$$\frac{\delta\Lambda}{\delta M} = P_M - \lambda F_M(K, L, M) = 0$$

$$\frac{\delta\Lambda}{\delta\lambda} = Y - F(K, L, M) = 0$$

This gives us four equations in four unknowns (K, L, M, λ). Hence, if we specify the production function, we can recover the demand function for each input and derive a cost function.

B.1. COBB-DOUGLAS

Firstly, let the production function take a Cobb-Douglas form so that $F(K, L, M) = AK^{\alpha_K}L^{\alpha_L}M^{\alpha_M}$ and the firm's minimisation problem is

$$\Lambda = \min_{K,L,M} P_K K + P_L L + P_M M + \lambda(Y - AK^{\alpha_K}L^{\alpha_L}M^{\alpha_M})$$

The first order conditions can be substituted back into the production function to find the associated cost function. Greene (2008) shows that this is

$$\ln C = \beta_0 + \beta_y \ln Y + \beta_K \ln P_K + \beta_L \ln P_L + \beta_M \ln P_M + \epsilon$$

With multiple outputs this extends to

$$\ln C = \beta_0 + \sum_{i=1} \beta_i \ln Y_i + \sum_{j=1} \beta_j \ln P_j + \epsilon$$

For our estimation we have adopted a simplified approach with regards to input prices. Costs are introduced after being deflated for assumed input prices. In this specification this has the same effect as introducing input prices but with a parameter restriction of 1. We consider an assumption that costs should be directly proportional to input prices to be reasonable.

Assuming firms produce outputs such that marginal costs equal prices, the prices of outputs can be recovered by taking the first derivative of this cost function with respect to each output

$$P_{Y_i} = \frac{\delta C}{\delta Y_i} = \frac{C\beta_i}{Y_i}$$

From this condition, we can construct output weights.

B.2. TRANSLOG

Instead of assuming a Cobb-Douglas production function and deriving the associated cost function, we can use a second-order Taylor series expansion to approximate any cost function that takes outputs and input prices as arguments. The log linearized version of this function is the translog function and can be written as

$$\ln C = \alpha_0 + \sum_{i=1} \mathrm{\alpha_i} \ln Y_i \; + \sum_{j=1} \alpha_j \ln P_j + \frac{1}{2} \sum_{i=1} \sum_{j=1} \beta_{ij} \ln Y_i \ln Y_j \; + \frac{1}{2} \sum_{k=1} \sum_{l=1} \beta_{kl} \ln P_k \ln P_l \; + \sum_{m=1} \sum_{n=1} \beta_{mn} \ln Y_m \ln P_n + \epsilon$$

As with the Cobb-Douglas function we adopt a simplification with regards to input prices.

Using a similar argument as before, the first derivative of the cost function with respect to each output can be used to recover prices.

$$P_{Y_i} = \frac{\delta C}{\delta Y_i} = \frac{C}{Y_i} \left(\alpha_i + 2\beta_{ii} \ln Y_i + \sum_{j \neq i} \beta_{ij} \ln Y_j + \sum_{m} \beta_{im} \ln P_m \right)$$

Given these prices we can construct output weights. The translog function allows for more general substitution between outputs given changes in input prices and allows cost to depend on outputs in a non-linear manner.

Appendix C ECONOMETRIC PARAMETER ESTIMATES

Full econometric model results, including parameter estimates and significance, are provided as .csv files alongside this report.

Filename	Description
CD_reg_output_TE_all.csv	Total expenditure model with Cobb-Douglas specification for all EDBs.
CD_reg_output_TE_Exempt.csv	Total expenditure model with Cobb-Douglas specification for exempt EDBs.
CD_reg_output_TE_NonExempt.csv	Total expenditure model with Cobb-Douglas specification for non-exempt EDBs.
CD_reg_output_Opex_all.csv	Opex model with Cobb-Douglas specification for all EDBs.
CD_reg_output_Opex_Exempt.csv	Opex model with Cobb-Douglas specification for exempt EDBs.
CD_reg_output_Opex_NonExempt.csv	Opex model with Cobb-Douglas specification for non-exempt EDBs.
TL_reg_output_TE_all.csv	Total expenditure model with Translog specification for all EDBs.
TL_reg_output_TE_Exempt.csv	Total expenditure model with Translog specification for exempt EDBs.
TL_reg_output_TE_NonExempt.csv	Total expenditure model with Translog specification for non-exempt EDBs.
TL_reg_output_Opex_all.csv	Opex model with Translog specification for all EDBs.
TL_reg_output_Opex_Exempt.csv	Opex model with Translog specification for exempt EDBs.
TL_reg_output_Opex_NonExempt.csv	Opex model with Translog specification for non-exempt EDBs.

Appendix D OUTPUT FIGURES

D.1. OUTPUT INDICES

Figure 27: Model 1 (Circuit length, ICPs)

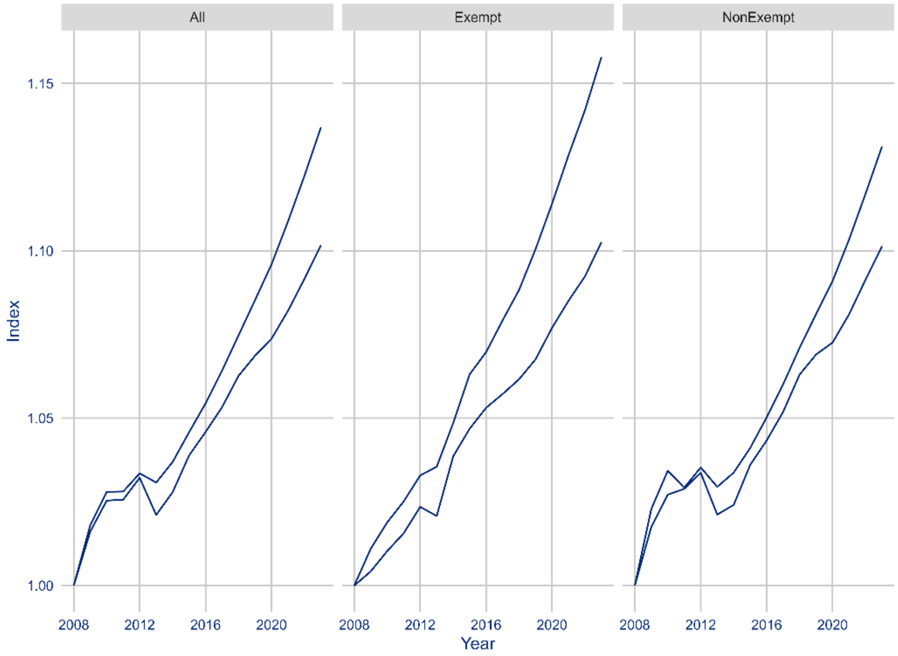


Figure 28: Model 2 (Energy delivered, customer numbers, transformer capacity)

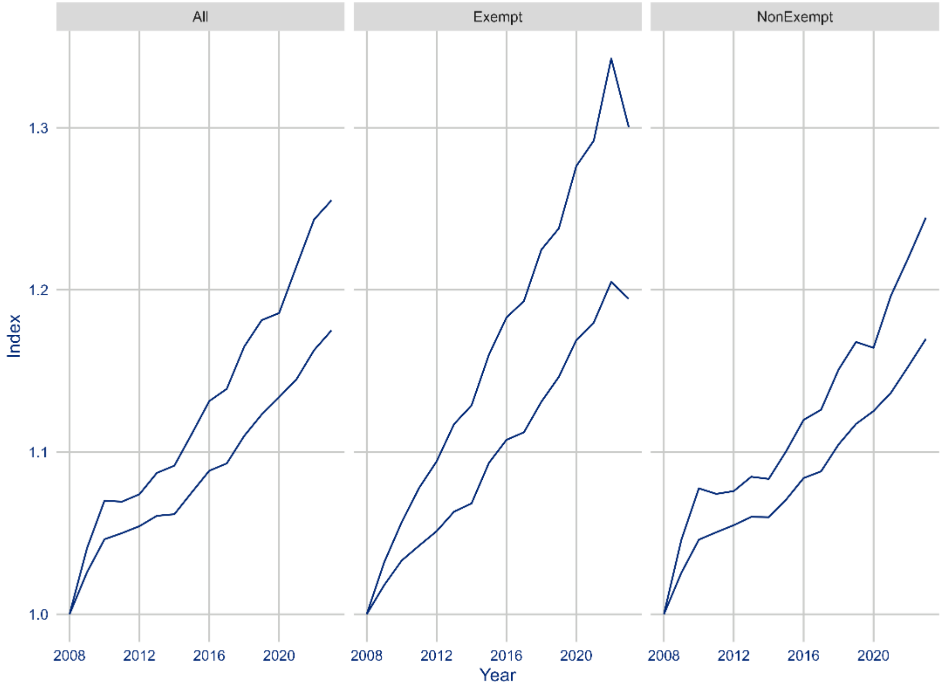


Figure 29: Model 3 (Energy delivered, ratcheted maximum demand, customer numbers, circuit length)

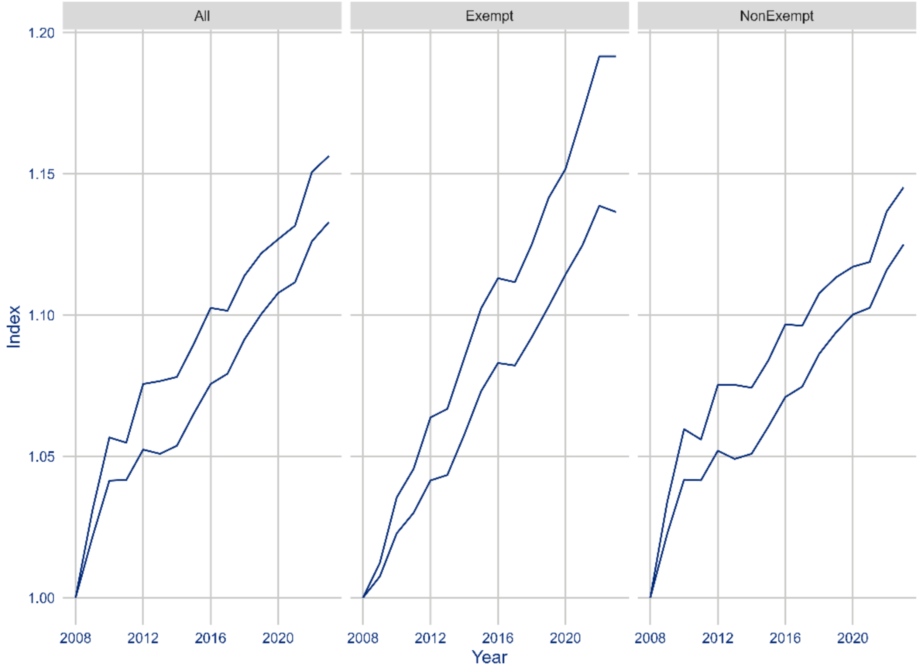


Figure 30: Model 4 (Ratcheted maximum demand, customer numbers, circuit length)

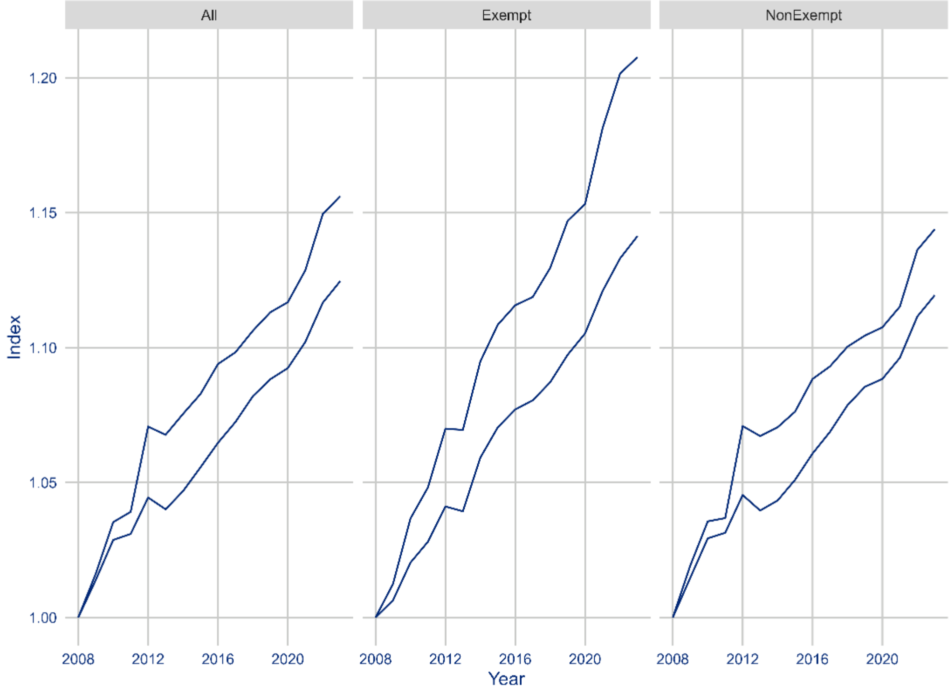


Figure 31: Model 6 (Ratcheted maximum demand, circuit length, transformer capacity)

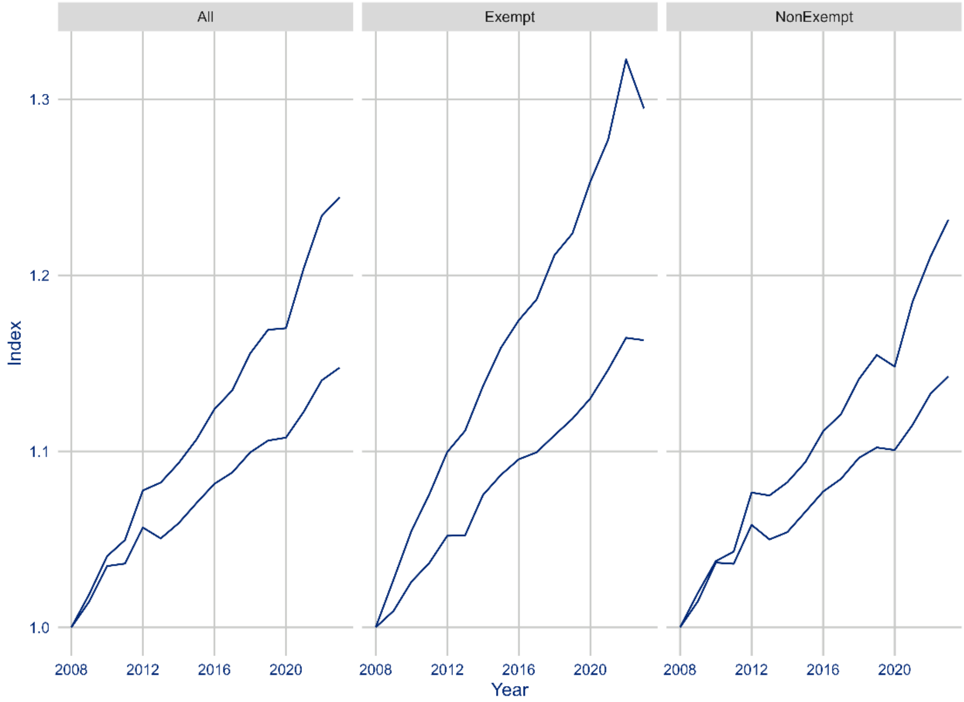


Figure 32: Model 7 (Ratcheted maximum demand, circuit length)

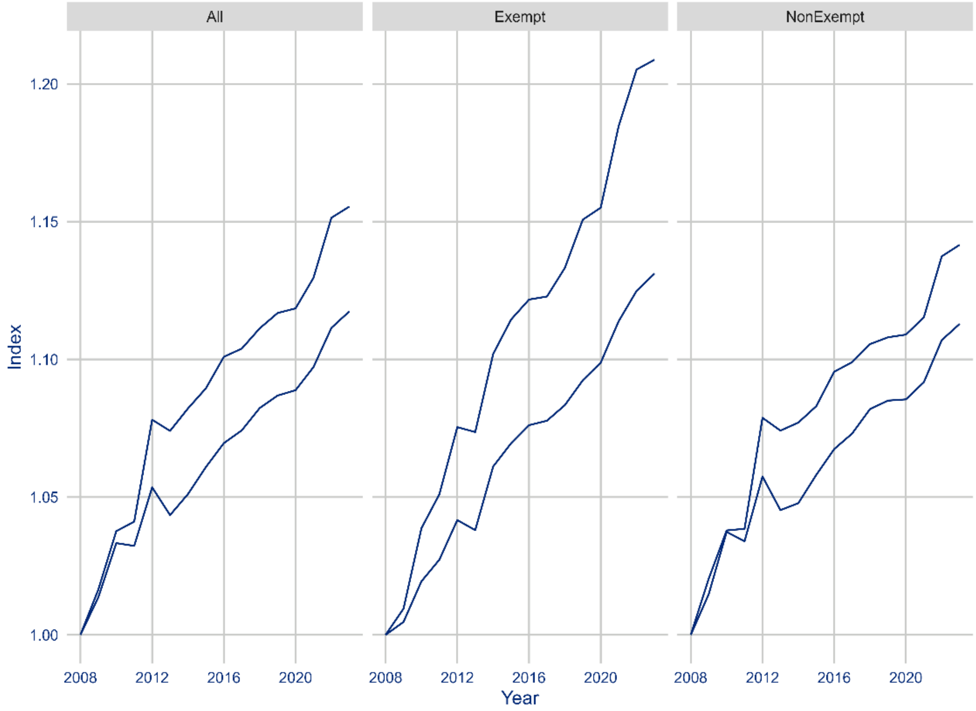


Figure 33: Model 8 (Customer numbers, overhead line capacity, underground cable capacity)

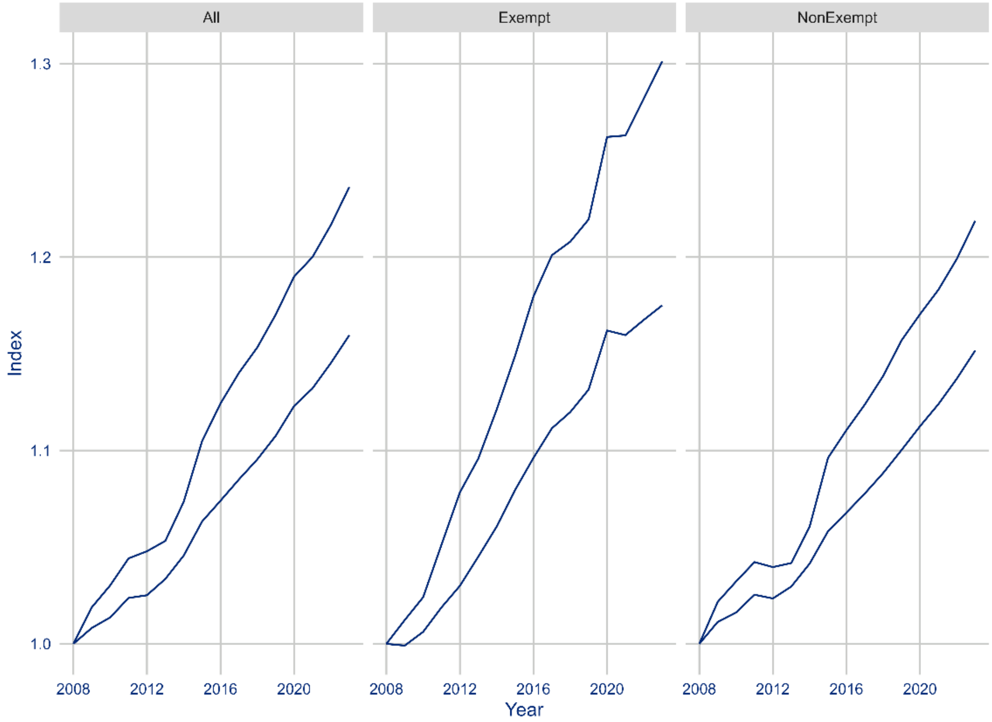
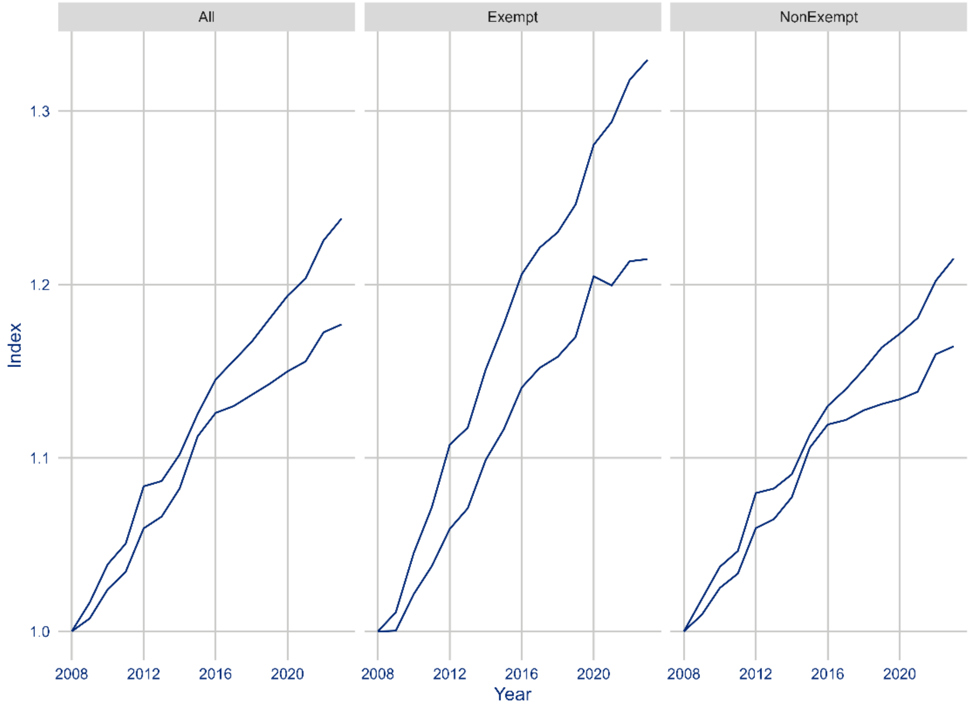


Figure 34: Model 9 (Ratcheted maximum demand, overhead line capacity, underground cable capacity)



Appendix E PREVIOUS STUDIES

There have been a large number of productivity studies looking at electricity distribution businesses and a surprisingly large variation in the choice of inputs and outputs. We consider that this variation reflects uncertainty in the literature on how to define the outputs of distribution networks.

Jamasb and Pollitt (2001) survey 20 benchmarking studies and find that the following outputs are chosen with the following frequencies:

- Units sold (GWh) – 12
- No. of customers – 11
- Service area (sq. kms) – 6
- Network size (kms) – 4
- Maximum demand (MW) – 4

The other outputs used in the studies include transformer capacity, power sold to other utilities, service reliability, load factor, net margin, revenues, distance index, and network density.

The choice of inputs and outputs in a selection of recent New Zealand and Australian studies are summarised in the table below.

Study	Outputs	Inputs
Economic Insights (2009a)	1. Throughput (GWh) 2. Customer numbers (n) 3. System capacity (line length times transformer capacity kVA-kms)	1. Opex ($/yr) 2. Overhead lines (MVA-kms) 3. Underground lines (MVA-kms) 4. Transformers (MVA)
PEG (2009)	1. Customer numbers (n) 2. Throughput (GWh) 3. Non-coincident peak demand (GW)	1. Opex ($/yr) 2. Capital ($/yr)
Quantonomics (2022)	1. Customer numbers 2. Circuit length (km) 3. Ratcheted maximum demand (MW) 4. Energy delivered (GWh) 5. Reliability (Minutes off supply)	1. Five types of physical capital assets 2. Opex

Appendix F REFERENCES

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UK

Queens House

55-56 Lincoln's Inn Fields

London WC2A 3LJ

T. **+44 (0)20 7269 0210**

E. **info@cepa.co.uk**

www.cepa.co.uk

Australia

Level 20, Tower 2 Darling Park

201 Sussex Street

Sydney NSW 2000

T. **+61 2 9006 1308**

E. **info@cepa.net.au**

www.cepa.net.au

Cepa-ltd

@cepaltd