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EDB Productivity Study

A report prepared for the Commerce Commission

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DRAFT REPORT

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Contents

EXECUTIVE SUMMARY

CEPA was engaged by the Commission to provide an 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 1.5% 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 has 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. This sits closer to 2% per year on average.

The table below shows the estimated change 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.

Table 1: Results by method (not including reliability models)

	Entire period – TFP	Entire period – Opex partial
Index-based	-1.2%	-1.9%
Econometric	-1.5%	-1.7%

In preparing this report we have 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. However, throughout this report we have sought to convey that the results reflect the data available as well as fundamental difficulties with measuring the productivity of EDBs.

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 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 ($)	44% higher
Real flow of capital services ($)	39% higher
Transformers (MVA)	32% higher
Overhead line capacity (MVA-KMs)	11% higher
Underground cable capacity (MVA-KMs)	40% higher
Connections (Count)	15% higher
Circuit length (KMs)	8% higher

Variable	Change between 2008 and 2023
Energy delivered (GWh)	15% higher
Maximum demand (GW)	11% higher
Ratcheted maximum demand (GW)	23% higher
Reliability – Planned minutes off supply[1]	4.3 times higher
Reliability – Unplanned minutes off supply	2.4 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

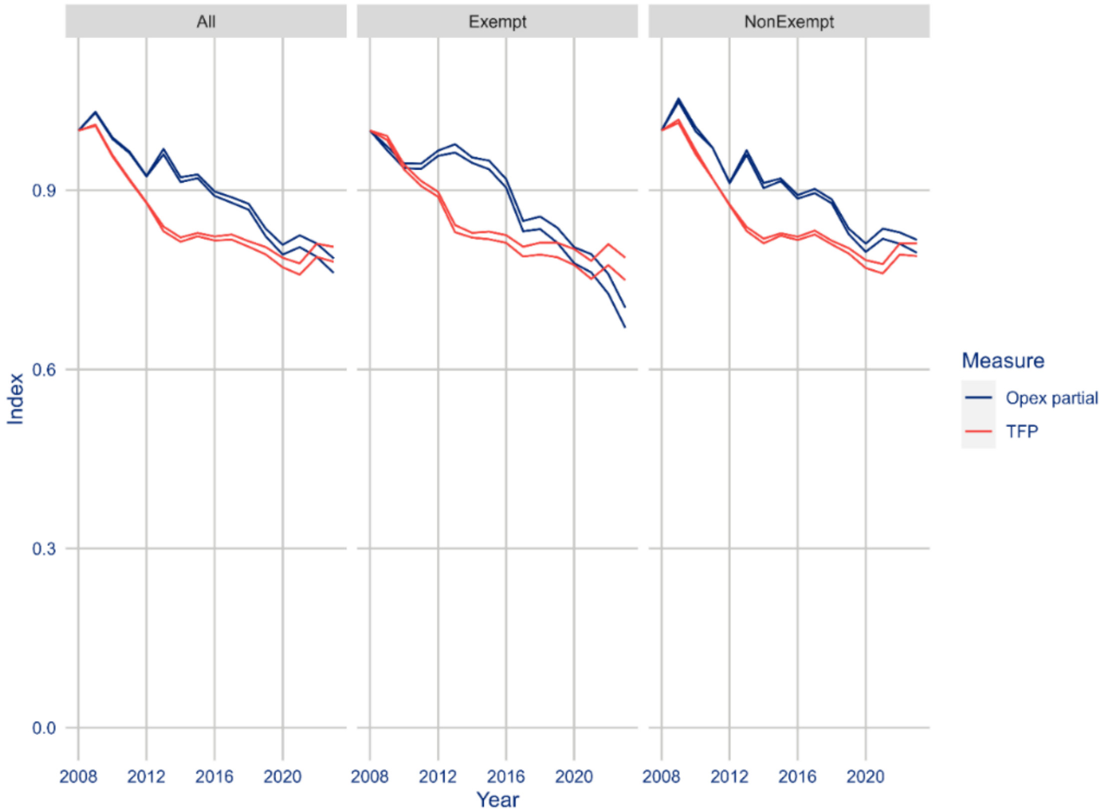
EDB type	Total factor productivity			Opex partial productivity		
	Entire period	Pre-2014	Post-2014	Entire period	Pre-2014	Post-2014
Non-exempt	-1.2%	-2.6%	-0.4%	-1.1%	-1.0%	-1.5%
Exempt	-1.3%	-2.6%	-0.7%	-1.9%	-0.3%	-3.3%
Overall	-1.2%	-2.5%	-0.5%	-1.3%	-0.8%	-2.0%

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 (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.

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

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. 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.

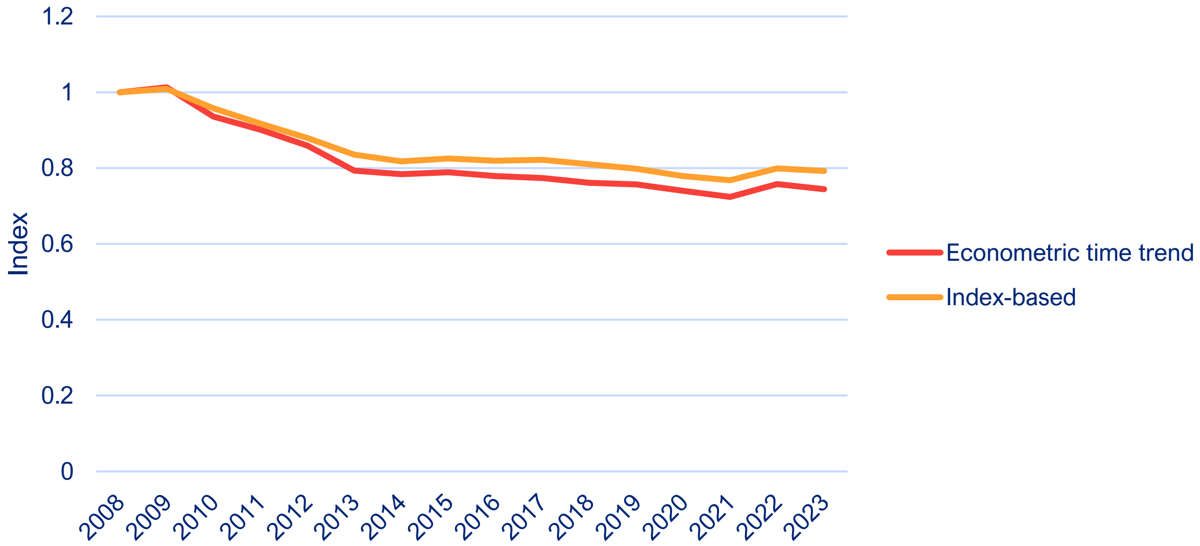
Table 4: Summary of key results – Econometric methods

Type	Entire period - TFP	Entire period - Opex
Non-exempt	-1.7%	-1.6%
Exempt	-1.1%	-1.9%
Overall	-1.5%	-1.7%

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 year-on-year changes in the productivity indices using the two approaches for one of our models. 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 year-on-year change for the index-based and econometric approach for Model 1



Source: CEPA analysis of Commerce Commission ID data.

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.

While the methods used here show an apparent decline in productivity, this could be an artefact of the modelling approaches used here, such as failing to correctly account for all of the outputs of an EDB, the difficulty in measuring the use of capital inputs, or other factors such as changing weather patterns.

1. INTRODUCTION

CEPA was engaged by the Commerce Commission to provide estimates of productivity changes in the EDB sector. This draft report sets out our findings for stakeholder comment.

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.

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 incredibly 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. 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. In addition, we highlight issues which we will explore further before this report is finalised, and on which the perspective of stakeholders could be valuable.

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

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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

[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.

[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

[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

[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.

[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.

[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.

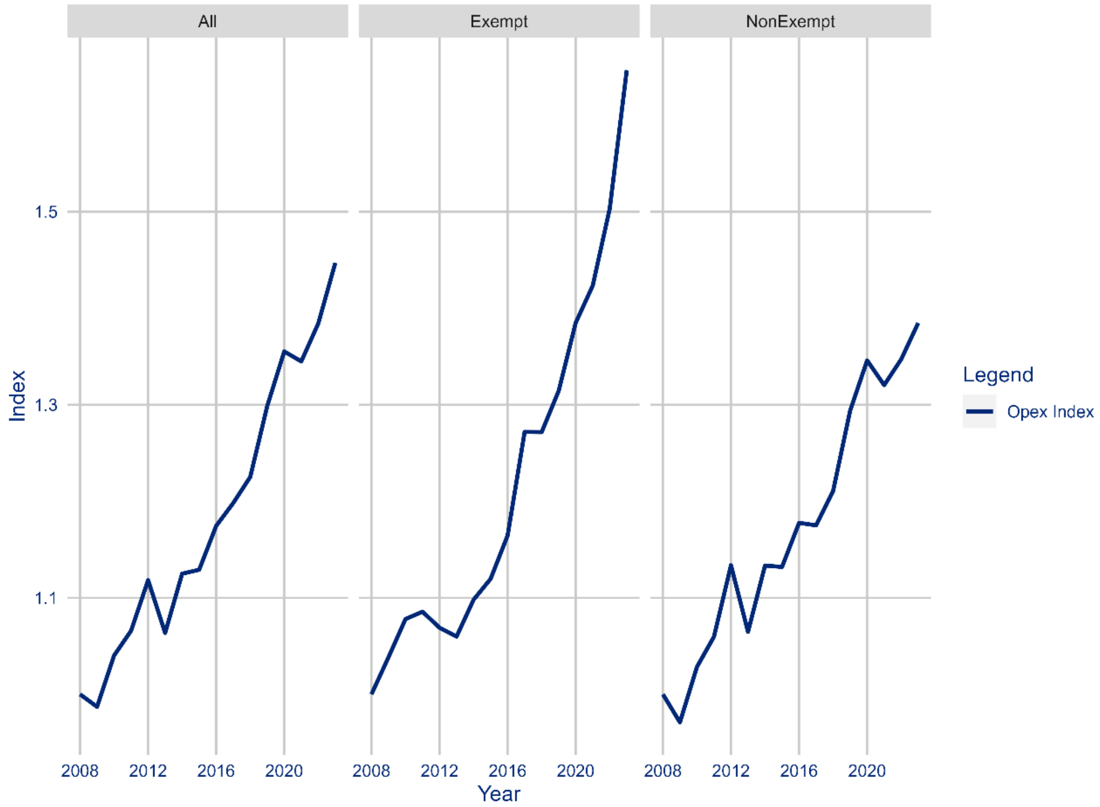
Our approach is the same as Economic Insights in the treatment of operating expenditure. As with Economic Insights, we have simply included operating inputs at their total cost in the input index. The difference with Economic Insights is in the treatment of the capital inputs.

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.

[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.

[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]

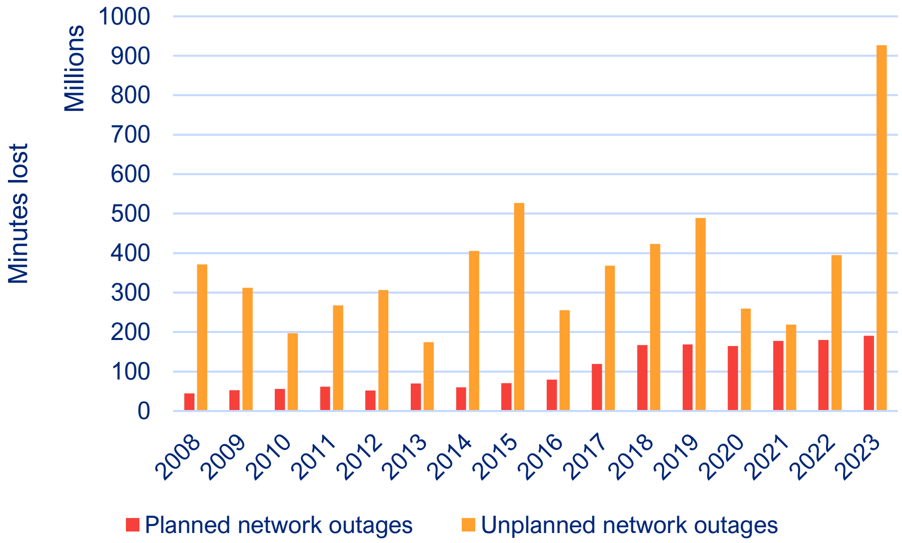
Aggregation of both planned and unplanned in one measure is more open to question. Both clearly represent service quality, a planned outage would still be seen as costly by customers. However, a planned outage would be seen as less costly than an unplanned outage. Nonetheless, for simplicity we combine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

[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 draft 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 is no data for Wellington Electricity in 2008. This is because Wellington Electricity demerged from Vector in 2009. We have made no special adjustments for this in the dataset.
- 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.

[17] Available from the Commission's website.

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.

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.

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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.

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:

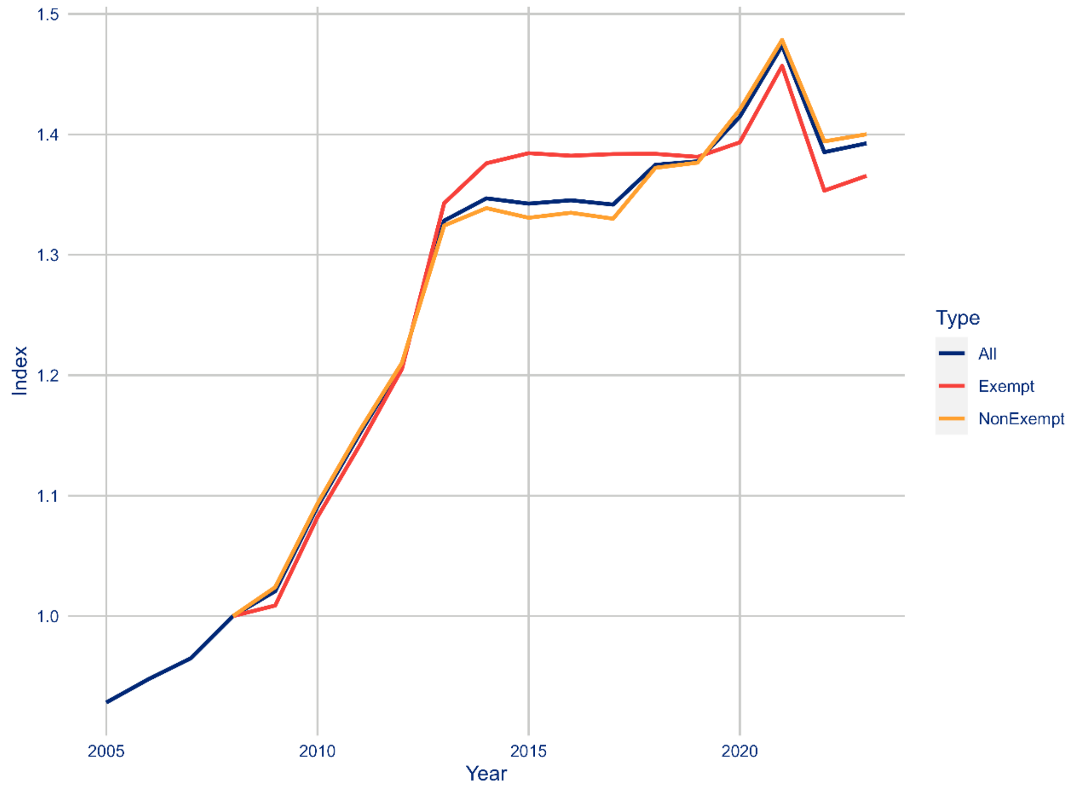
- The flow of capital services on an annual basis is assumed to be proportional to the productive capital stock, as proxied by the size of the Regulatory Asset Base.
- To estimate the total rental cost of capital, we use the approach in the previous productivity study – this involves applying an 'amortisation-based 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. The cost of capital is assumed to be 6.05% 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.

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

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.

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.

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 ln of the cost of firm j at time t.
- β_o is a constant term
- β_i is the power (the elasticity) of output i
- x_{jit} is the ln 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.

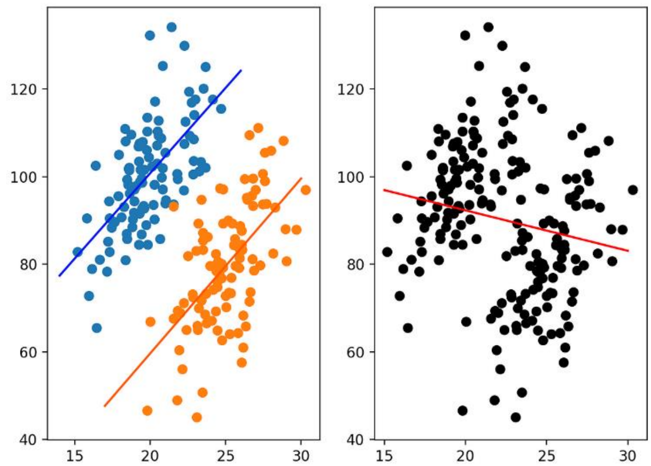
$$C_{jt} = \beta_o + \sum_{i=1}^{M} \beta_i\, x_{jit} + 0.5 \sum_{i=1}^{M} \sum_{i=1}^{M} \beta_i\, x_{jit}\, x_{jit} + \beta_{M+1} t \quad + D_j + v_{jt}$$

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.

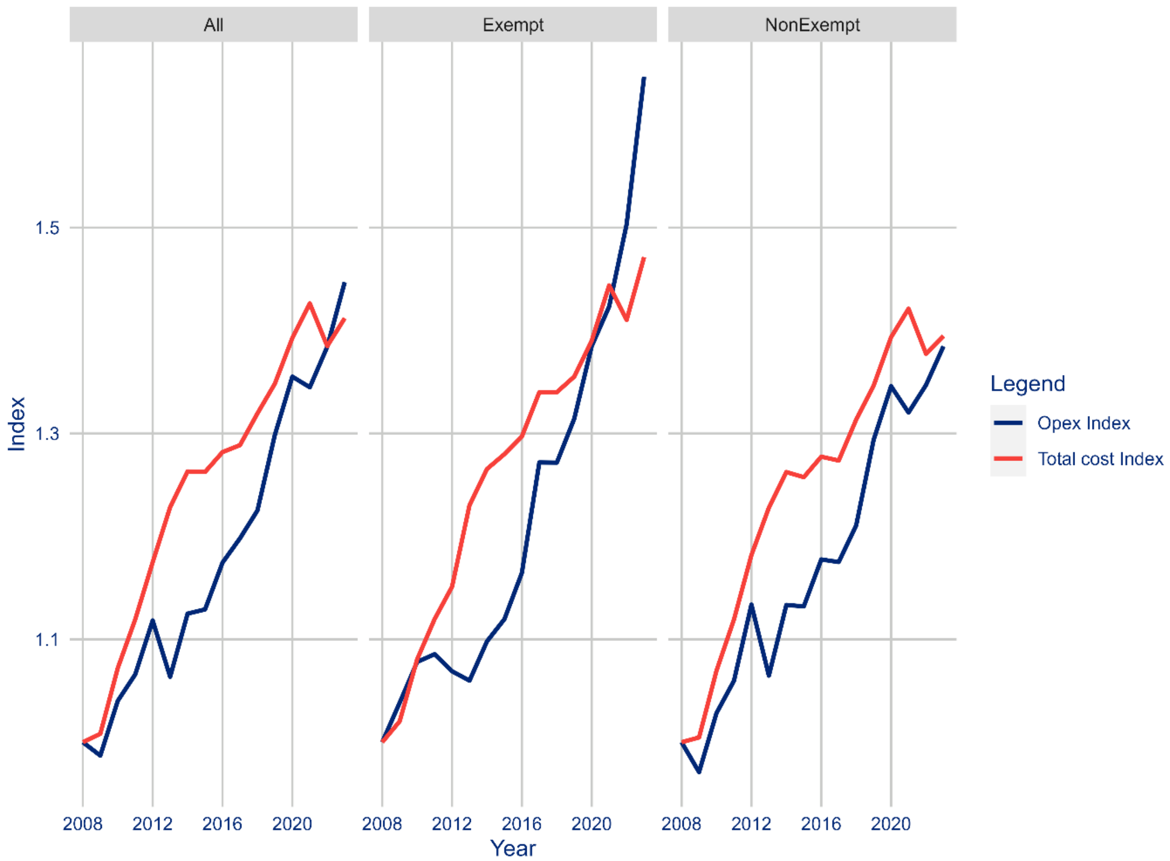
4.1. INPUT INDICES

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)

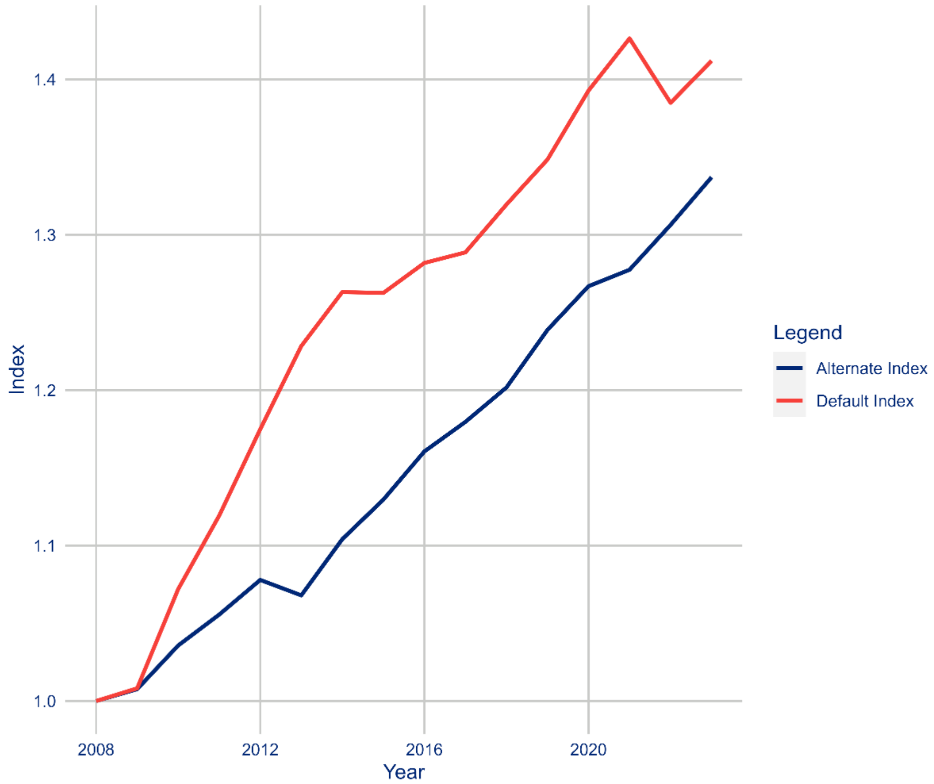


Source: CEPA analysis of Commerce Commission ID data.

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).[21] 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:

[21] 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.

- **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.
- **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

Model number	Number of outputs	Outputs
		• 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.[22] 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.

[22] 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	Output Prices (FE)
1	Circuit length: $3,269* ICPs: $330*	Circuit length: $2,114* ICPs: $187*
2	Energy: -$3,423 ICPs: $163* Capacity: $41,882*	Energy: $16,096* ICPs: -$111 Capacity: $13,702*
3	Energy: -$4,852 Ratch. Max.: $64,724* ICPs: $175* Circuit length: $3,387*	Energy: $12,557* Ratch. Max.: $80,680* ICPs: -$163 Circuit length: $2,987*
4	Ratch. Max.: $47,086* ICPs: $171* Circuit length: $3,244*	Ratch. Max.: $117,098* ICPs: -$80 Circuit length: $3,074*
5	Circuit length: $3,042* Connections: $330* SAIDI B: $0.178 SAIDI C: $0.021	Circuit length: $2,080* Connections: $173* SAIDI B: $0.010 SAIDI C: $0.025
6	Ratch. Max.: $55,800* Circuit length: $3,153* Capacity: $14,814*	Ratch. Max.: $97,192* Circuit length: $2,393* Capacity: $7,381
7	Ratch. Max.: $88,943* Circuit length: $3,619*	Ratch. Max.: $111,386 Circuit length: $2,789
8	ICPs: $328 Overhead:[23] $387 Underground: $1,983	ICPs: $72 Overhead: $314 Underground: $1,134
9	Ratch. Max.: $84,134 Overhead: $422 Underground: $2,424	Ratch. Max.: $94,022 Overhead: $258 Underground: $642

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. 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.[24] 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.

[23] MVA-kms

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

As we are unable to estimate an intuitive cost-based price we need an alternative for reliability. In Australia the benchmarking and productivity studies recently completed for the AER do not use cost information to generate prices for reliability. This contrasts with the other outputs where cost estimates are used for prices. It is not entirely clear why this decision was made. However, consultants for the AER may have encountered similar issues as us when attempting to generate intuitive costs for reliability using the available data.

The method applied in Australia involves using an estimate of the value of customer reliability (VCR). This value was initially generated by the AER in 2019.[25] A VCR attempts to reflect the value customers place on reliable electricity under different conditions and the AER presents this figure on a $/kWh basis. A single VCR value is difficult to estimate as the value customers place on reliable electricity is likely to be situation and time dependent. For example, a longer unplanned interruption is likely to be more costly than a short planned one. The VCR developed by the AER is meant to reflect the value a customer places on an unplanned outage of up to 12 hours. These are then separated out by customer type and location.

To recover a price for reliability, our starting point is to use the AER's VCR value along with a similar methodology as applied in the AER's recent benchmarking and productivity studies. This makes the assumption that New Zealand customers value reliability the same as Australian customers. This assumption is unlikely to be exactly correct, but our judgement is that it allows us to convert the AER's VCR to a New Zealand VCR with approximately the correct magnitude. We implement the following methodology:

- Use the AER's Australian NEM wide residential VCR value for 2019 of $AUD 24.08/kWh converted to New Zealand dollars at rate of 1.04 to produce a value of $NZ 25.04.

Adjust the 2019 value using New Zealand CPI to recover the real 2005 value of $19.16 which is then applied for the remainder of the analysis.[26]

- Calculate energy delivered per customer minute. This is done by first calculating the energy delivered per minute and then dividing this by total customer numbers. This produces a result of around 0.03 kWh depending on year. This represents the average kWh loss from a minute off supply.
- Multiply the energy delivered per customer minute by the VCR value to produce a cost per minute off supply. This produces a cost of around $0.54 per minute off supply varying by year.

An estimate of $NZ 0.54 per minute off supply appears low relative to that used in the recent Australian Quantonomics study of around $AUD 0.96 in 2006.[27] The primary reason for this is our use of a residential number with Australian commercial and industrial VCRs being much higher. With a breakdown of customer types by EDB it would be possible to refine this estimate. Furthermore, we intend to use the same value for planned and unplanned interruptions.

We cannot simply apply an estimate of VCR as the price of reliability alongside our cost-based prices. VCRs and cost-based prices attempt to represent different concepts. A VCR is an estimate of consumer surplus lost due to power failure. It seems almost certain that this will be a much larger than estimates of prices based on EDB costs. Furthermore, our assumption for the cost-based prices is that they need only be correct relative to each other not some external benchmark. Introducing an external price into this framework is not valid.

This suggests some sort of scaling is appropriate, otherwise reliability will be substantially overweight in our productivity model. Indeed, introducing minutes lost with a price of -$0.54 per minute means that productivity outcomes are driven solely by minutes lost and no other factor. This is clearly demonstrated in the figure below. 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

[25] AER (2019), Values of Customer Reliability, - Final report on VCR values.

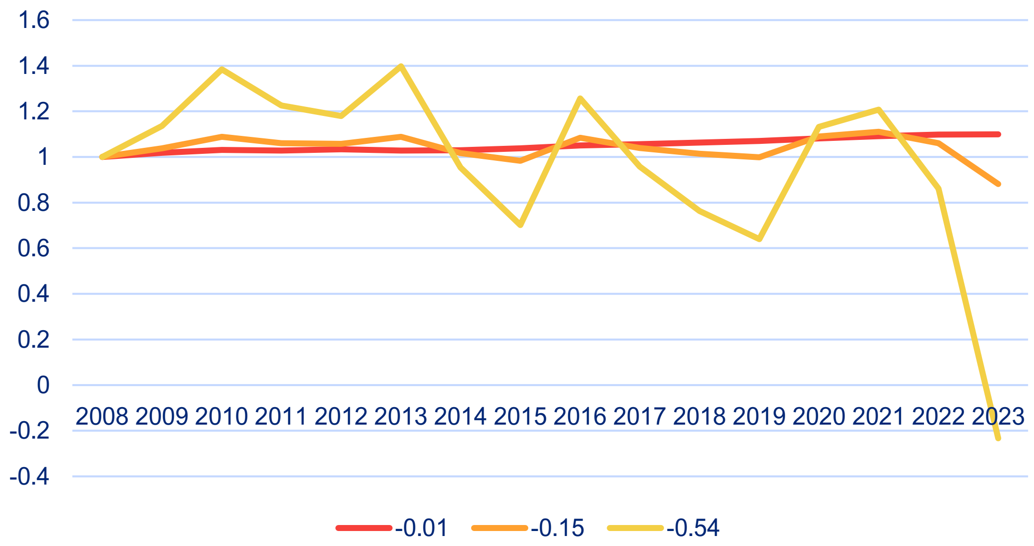
[26] We represent real prices in 2005 terms throughout this report.

[27] Quantonomics (2022), 2021 AER VCR Values.xlsx.

$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. We offer two alternatives which form our low and high prices for reliability.

Figure 8: Impact of reliability price assumption on output index



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

Our first proposal produces a price of -$0.15 which involves adjusting the -$0.54 so it is in line with our modelled prices. Our proposed adjustment is 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.
- 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 is for a low-end sensitivity with a value of -$0.01. The justification for this value is simply that the VCR value represents a much higher price than would be charged by EDBs if there were a separate reliability output. This means there is some justification for scaling down further from -$0.15.

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 4.3: Proposed min-max output prices

Output	Proposed price range
Circuit length (kms)	$2000 - $4000
Customer numbers	$100 - $400
Energy (GWh)	$13,000 - $16,000

Output	Proposed price range
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 4.4: Output index positions in 2023 minimum/maximum

Model	All: Min/Max	Exempt: Min/Max	Non-exempt: Min/Max
Model 1: Circuit length/customer numbers	1.11/1.14	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.	1.14/1.18	1.14/1.19	1.14/1.17
Model 4: Ratcheted maximum demand,	1.14/1.18	1.14/1.20	1.14/1.18

Model	All: Min/Max	Exempt: Min/Max	Non-exempt: Min/Max
customer numbers, circuit length.			
Model 5: Circuit length, connections, reliability	0.88/1.13	0.97/1.15	0.83/1.12
Model 6: Ratcheted maximum demand, circuit length, transformer capacity	1.16/1.25	1.16/1.29	1.16/1.24
Model 7: Ratcheted maximum demand, circuit length	1.13/1.18	1.13/1.20	1.13/1.18
Model 8: Customer numbers, overhead line capacity, underground cable capacity	1.16/1.24	1.18/1.30	1.15/1.21
Model 9: Ratcheted maximum demand, overhead line capacity, underground cable capacity	1.20/1.26	1.21/1.32	1.20/1.24

Source: CEPA analysis of Commerce Commission ID data.

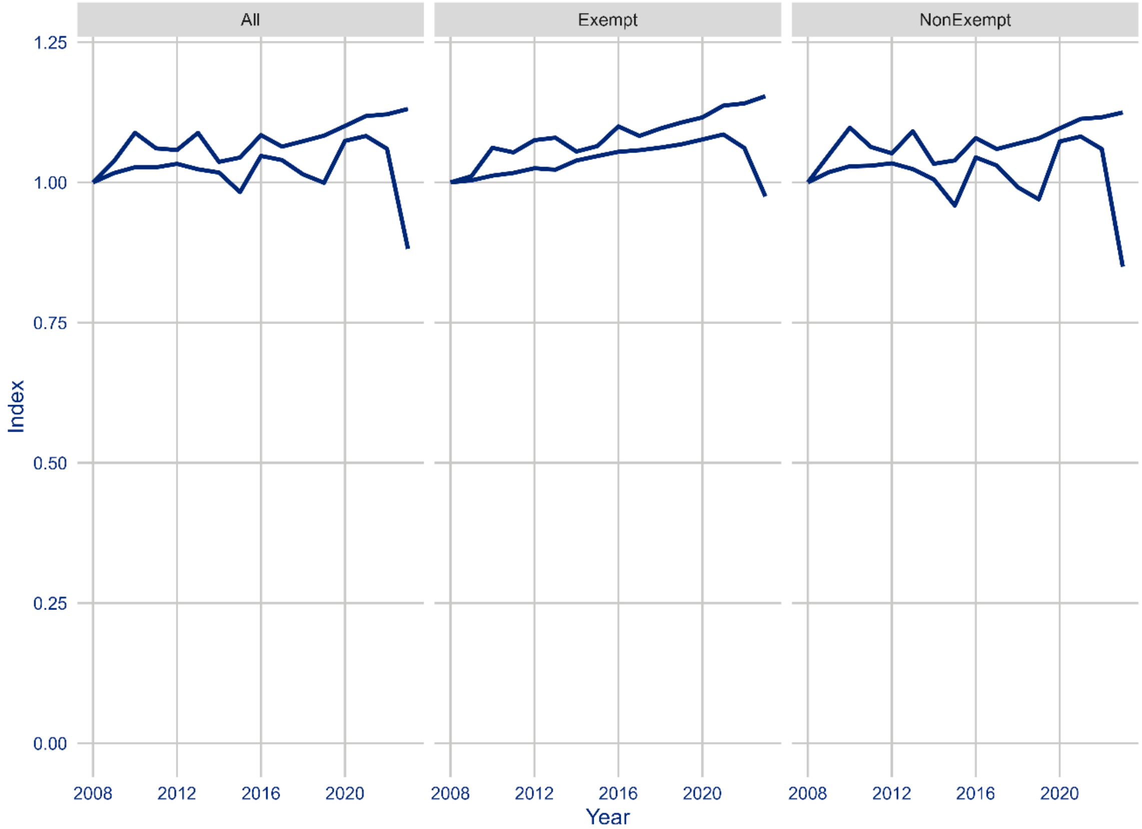
Reliability

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 our model which includes reliability. The two lines represent the minimum and maximum positions depending on the prices. There include three outputs in the model representing customer numbers, circuit length and reliability (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.

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 9: Model 5 (Circuit length, Connections, reliability)



Source: CEPA analysis of Commerce Commission ID data.

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 10 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.[28] 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.

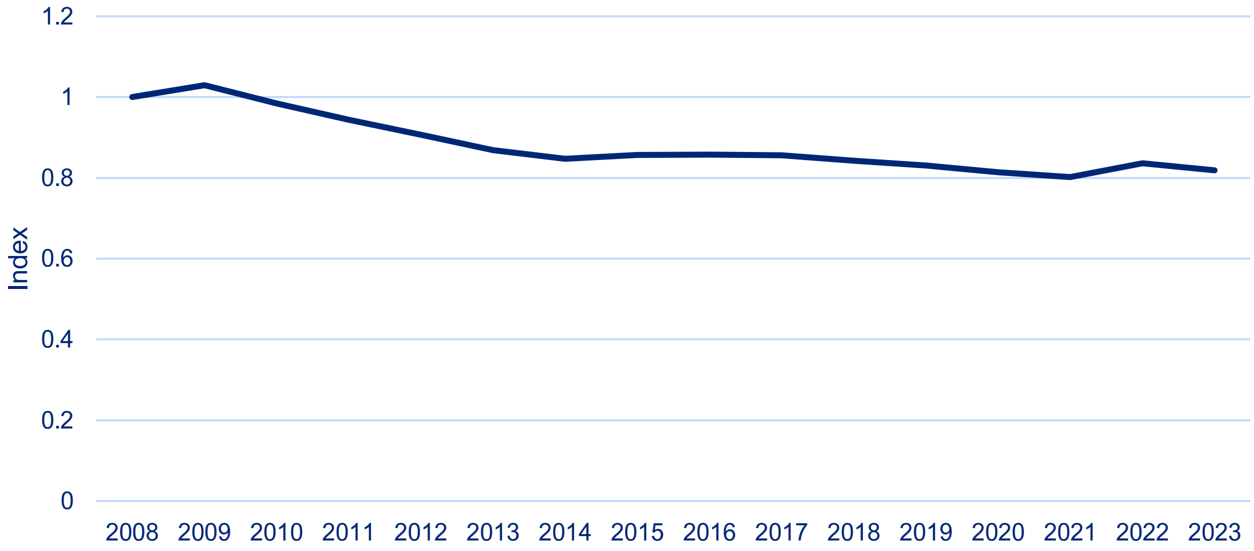
In terms of the opex partial productivity index there are differences between non-exempt and exempt EDBs. This is demonstrated in Figure 11 below which shows the productivity indices for model 1. The opex partial productivity index is shown as the blue line and for exempt EDBs there is a more substantial drop-off in the more recent period.

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

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.

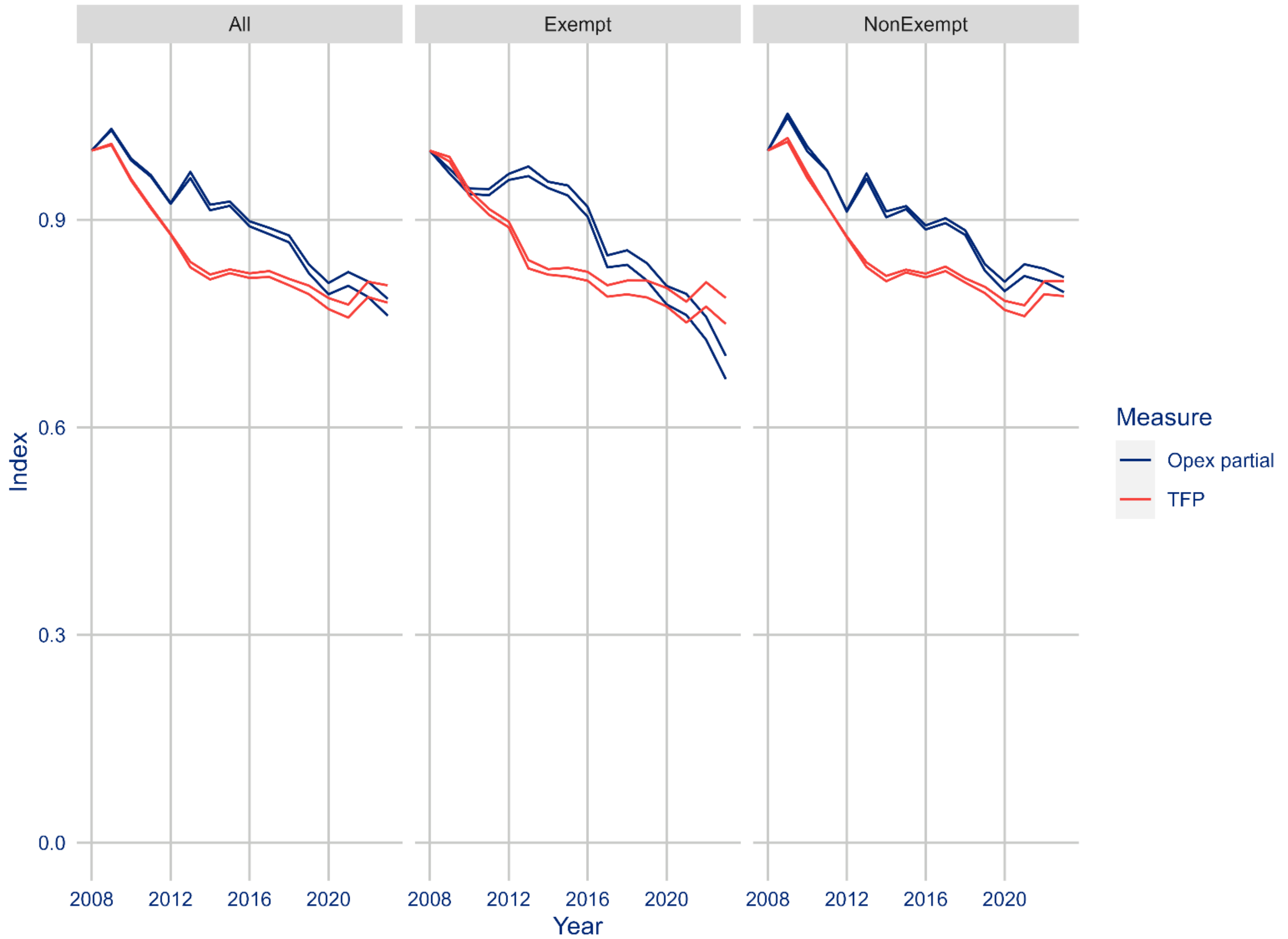
Figure 10: Average total factor productivity index – Overall industry – Not including reliability[29]



Source: CEPA analysis of Commerce Commission ID data.

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

Figure 11: Model 1 - Productivity indices (Output: Circuit length/ICPs)



Source: CEPA analysis of Commerce Commission ID data.

Table 4.5: Total factor 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	0.78	0.80	0.74	0.78	0.78	0.81
Model 2: Energy/customer numbers/capacity	0.83	0.88	0.81	0.88	0.83	0.89
Model 3: Energy/ratcheted max. demand/customer numbers/circuit length	0.80	0.83	0.77	0.80	0.81	0.83
Model 4: Ratcheted max. demand/customer	0.80	0.83	0.77	0.82	0.81	0.84

Model	All: Min	All: Max	Exempt: Min	Exempt: Max	Non-exempt: Min	Non-Exempt Max
numbers/circuit length						
Model 5: Circuit length/customer numbers/reliability	0.62	0.80	0.66	0.78	0.60	0.80
Model 6: Ratcheted maximum demand/circuit length/capacity	0.82	0.88	0.79	0.87	0.83	0.89
Model 7: Ratcheted max. demand/ circuit length	0.80	0.84	0.76	0.82	0.81	0.84
Model 8: Customer numbers/overhead/ underground	0.82	0.87	0.79	0.88	0.82	0.87
Model 9: Ratcheted max. demand/overhead/ underground	0.85	0.89	0.82	0.90	0.85	0.88
Average across specifications (non-reliability)	**0.82**	**0.85**	**0.78**	**0.84**	**0.82**	**0.86**

Source: CEPA analysis of Commerce Commission ID data.

Table 4.6: 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	0.78	0.66	0.70	0.79	0.81
Model 2: Energy/customer numbers/capacity	0.81	0.86	0.72	0.78	0.84	0.89
Model 3: Energy/ratcheted max. demand/customer numbers/circuit length	0.78	0.81	0.69	0.72	0.81	0.84
Model 4: Ratcheted max. demand/customer numbers/circuit length	0.78	0.81	0.69	0.73	0.82	0.84

Model	All: Min	All: Max	Exempt: Min	Exempt: Max	Non-exempt: Min	Non-Exempt Max
Model 5: Circuit length/customer numbers/reliability	0.60	0.78	0.59	0.70	0.61	0.81
Model 6: Ratcheted maximum demand/circuit length/capacity	0.80	0.86	0.70	0.78	0.83	0.89
Model 7: Ratcheted max. demand/ circuit length	0.78	0.82	0.68	0.73	0.81	0.85
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	0.82	0.86	0.73	0.80	0.86	0.89
Average across specifications (non-reliability)	**0.79**	**0.83**	**0.70**	**0.75**	**0.82**	**0.86**

Source: CEPA analysis of Commerce Commission ID data.

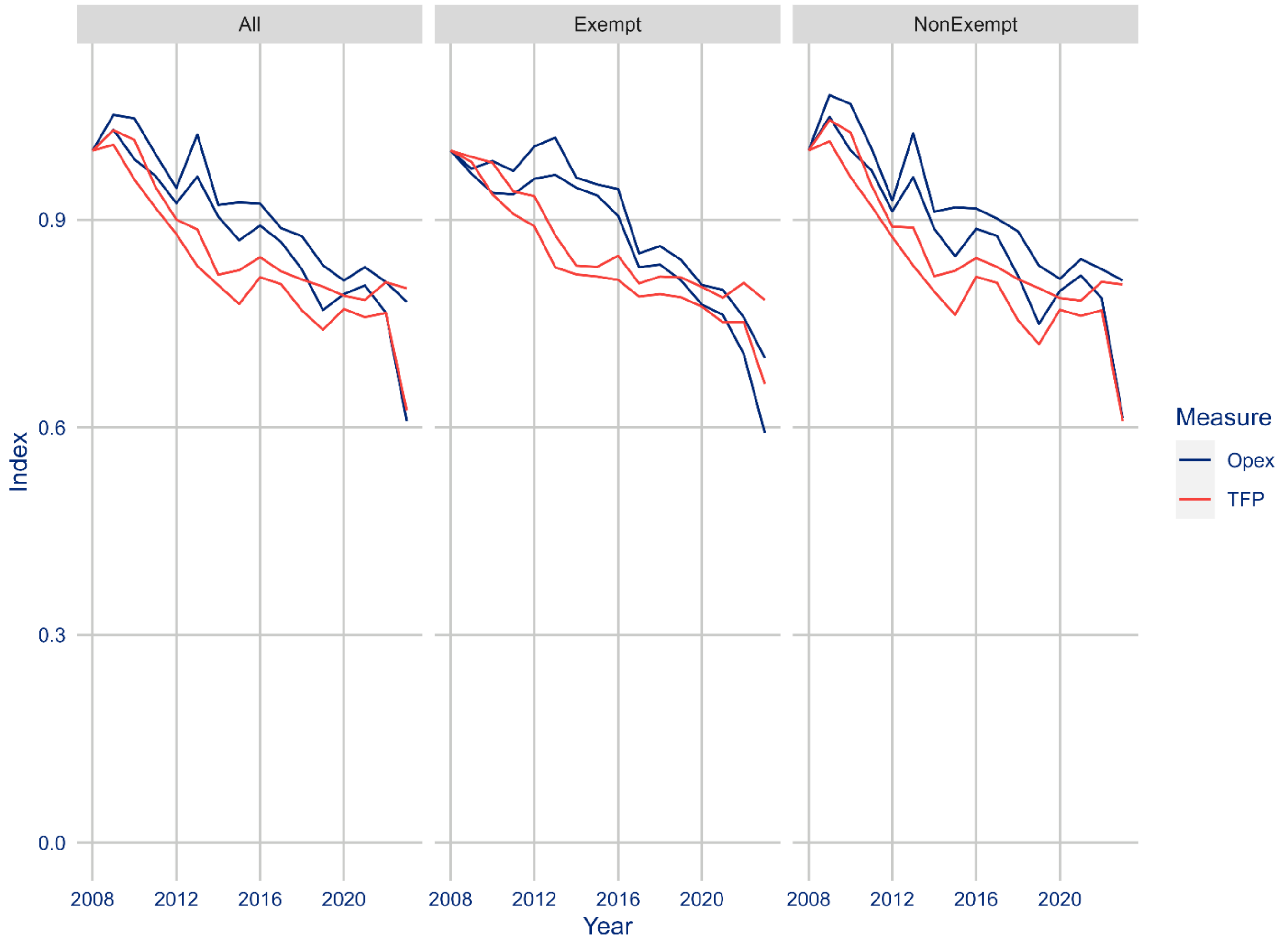
Reliability

The figure below shows the productivity indices for our model which includes reliability. The productivity index is falling regardless. However, inclusion of reliability exacerbates this trend.

In terms of the total factor productivity index the ending position for the industry overall is between 0.61 and 0.80 relative to the average of the non-reliability models of between 0.82 and 0.85. For exempt EDBs this is between 0.66 and 0.78 relative to 0.78 and 0.84 and for non-exempt EDBs this 0.61 and 0.81 relative to 0.82 and 0.86. This demonstrates the fact that total minutes lost was higher in 2023 than in 2008 and also the importance of the price at which you incorporate reliability.

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. Separating out these reasons is difficult even for seemingly external events such as cyclones. In terms of productivity, strengthening the network to withstand weather events would increase the input index but could potentially pay dividends on the output side.

Figure 12: Productivity indices - Model 6 (Outputs: Circuit length, Connections, Total minutes lost)



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.[30] 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.

[30] 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.

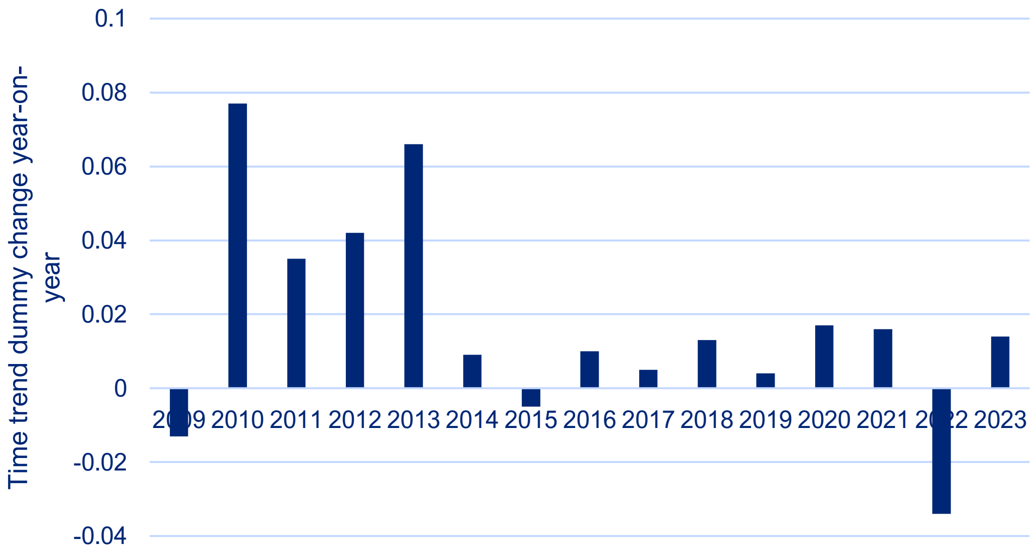
5.3. Year dummies

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.

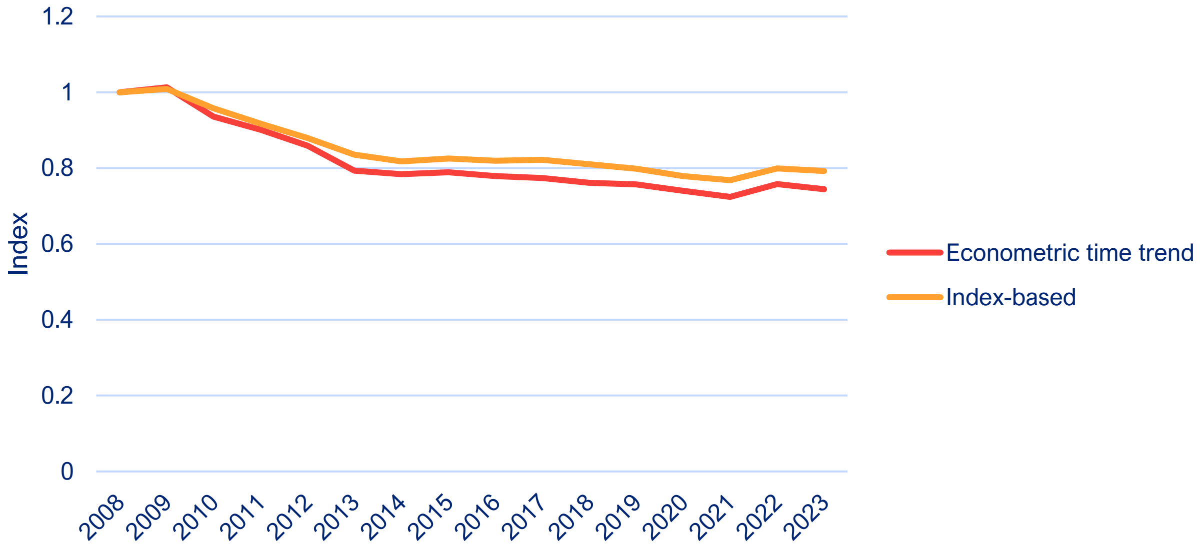
Figure 13: Time trend dummy estimates with year dummies – Model 1 – All EDBs - Year-on-year changes



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 14: 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 ***	0.020 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.015 ***	0.018 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.022 ***	0.015 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.022 ***	0.014 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.019 ***	0.019 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.017 ***	0.014 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.021 ***	0.016 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.017 ***	0.018 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.012 ***	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	0.021 ***	0.022 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.013 **	0.017 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.020 ***	0.013 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.020 ***	0.012 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.022 **	0.023 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.016 ***	0.010 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.020 ***	0.014 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.015 ***	0.019 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.008 **	0.015 ***

***** 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 ***

**** 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 ***	0.02 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.009 ***	0.019 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.016 ***	0.017 ***
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	0.014 ***	0.014 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.016 ***	0.015 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.012 ***	0.019 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.010 ***	0.015 ***

**** 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 ***	0.024 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.012 **	0.021 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.018 ***	0.017 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.018 ***	0.016 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.019 **	0.025 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.017 ***	0.015 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.018 ***	0.016 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.016 ***	0.022 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.013 ***	0.017 ***

**** 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	0.010 **	0.014 ***
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	0.014 ***	0.011 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.009 **	0.013 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.010 ***	0.009 ***
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	0.003	0.006 *

***** *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 ***	0.020 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.012 ***	0.020 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.024 ***	0.022 ***
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 ***	0.017 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.015 ***	0.018 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.010 ***	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 ***	0.023 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.017 ***	0.016 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.023 ***	0.021 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.019 ***	0.013 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.023 ***	0.026 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.015 ***	0.013 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.020 ***	0.017 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.013 ***	0.019 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.004	0.015 ***

**** 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 ***

**** 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 ***	0.02 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.008 **	0.02 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.019 ***	0.022 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.017 ***	0.017 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.014 ***	0.018 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.014 ***	0.014 ***
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 ***	0.012 ***

**** 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 ***	0.024 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.017 ***	0.021 ***
3	• Volumes Carried • Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.02 ***	0.027 ***
4	• Ratchet Maximum Demand • Number of Connections • Total Circuit Length	0.019 ***	0.016 ***
5	• Total Circuit Length • Number of Connections • Reliability	0.021 ***	0.025 ***
6	• Ratchet Maximum Demand • Total Capacity • Total Circuit Length	0.016 ***	0.016 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.019 ***	0.016 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.011 ***	0.022 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.006 *	0.016 ***

***** *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	0.015 ***	0.017 ***
2	• Volumes Carried • Number of Connections • Total Capacity	0.007	0.017 ***
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 ***	0.008 ***
7	• Ratcheted Maximum Demand • Total Circuit Length	0.013 ***	0.01 ***
8	• Number of Connections • Overhead Line Capacity • Underground Cable Capacity	0.005 *	0.011 ***
9	• Ratchet Maximum Demand • Overhead Line Capacity • Underground Cable Capacity	0.002	0.008 ***

**** 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. Some of the potential reasons for this have been raised by EDBs in recent feedback to the Commission on other work. This has primarily been in the context of operating expenditure. We summarise some of the reasons raised in Section 6.2 with a focus on operating expenditure rather than total expenditure as that was the context that these comments were provided.

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.
- 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.
- Reliability is not being correctly valued. For example:

  It may be that unusual weather patterns resulted in an increase in operating expenditure over this period, masking improvements in service quality and resilience.
- 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.

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[31]. 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.
- **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

[31] 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.

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[32], 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.

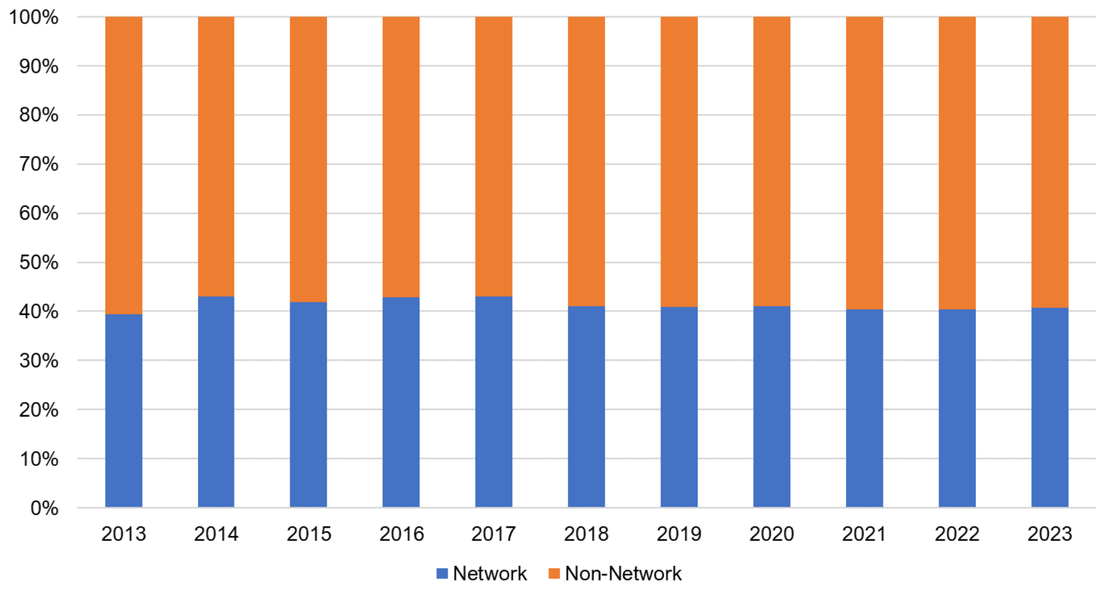
Table 6.1: Operating expenditure cost disaggregation available in EDB information disclosure

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 16 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).

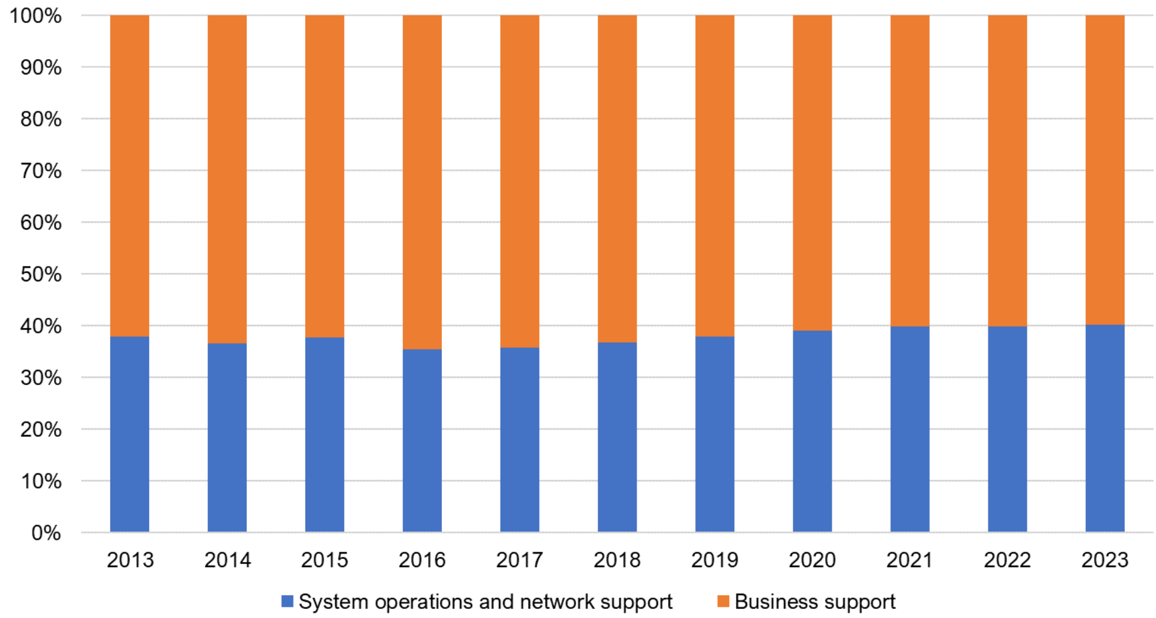
[32] This time period has been used as the disaggregation of opex currently reported by the EDBs is not available pre-2013

Figure 15: 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 16: Proportions of non-network operational expenditure across all EDBs



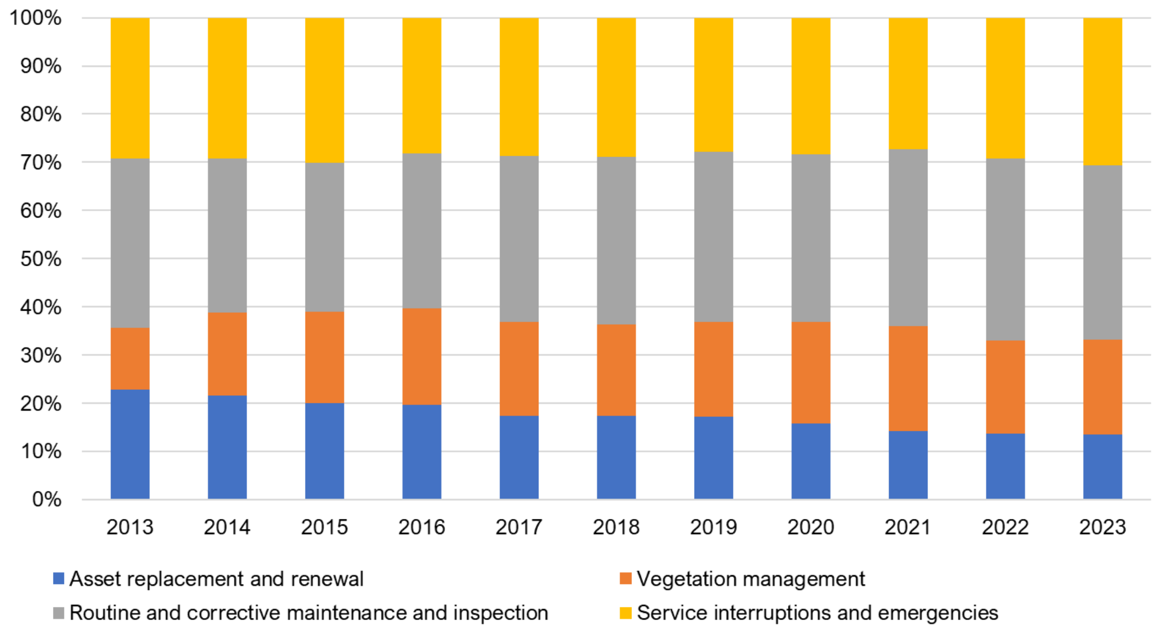
Regarding the components of network opex:

- **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 17: 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. POTENTIAL AREAS TO EXAMINE AT CONSULTATION

As we undertook this work, we identified potential additional avenues which it may be valuable to explore further. Some of these relate to the problem that there may be missing outputs that are not included in the analysis, while others may help bring further context to the results. We would value stakeholder input on the relevance of these issues and potential data sources to allow for their inclusion. Some of these issues include:

- Over the period, there were changes to working practices. While changes in reliability may have worsened productivity, these may be offset by improved health and safety outcomes. We have not explicitly included health and safety outcomes.
- We have included reliability as simply as possible, that is using minutes lost. However, this is not the only way to represent reliability, and there are a range of transformations or adjustments that could be considered.
- We have applied a value of customer reliability which was converted from an Australian context. There may be more relevant New Zealand values that could be applied.
- EDB services may be changing and one of those may be responding to more two-way flows from distributed energy resources. It is possible that an output could be constructed to take this into account.
- We have included the flow of capital services using one particular methodology. Sensitivity analysis could be considered.

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)

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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

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

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

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

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

C.1. Cobb-Douglas Model Results

C.1.1. Operating Expenditure

All EDBs

	Model 1	Model 1 (FE)
Intercept	-36.888 (4.719) ***	-34.606 (3.297) ***
Number of Connections	0.555 (0.015) ***	1.029 (0.225) ***
Total Circuit Length	0.348 (0.018) ***	0.078 (0.202)
Year	0.022 (0.002) ***	0.02 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-20.587 (6.238) **	-28.665 (4.375) ***
Volumes Carried	-0.203 (0.066) **	0.39 (0.196) *
Number of Connections	0.422 (0.04) ***	0.469 (0.255)
Total Capacity	0.632 (0.076) ***	0.247 (0.135)
Year	0.015 (0.003) ***	0.018 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-35.96 (4.702) ***	-24.916 (3.804) ***
Volumes Carried	0.003 (0.071)	0.235 (0.186)
Ratcheted Max Demand	0.073 (0.064)	0.654 (0.18) ***
Number of Connections	0.48 (0.036) ***	0.383 (0.24)
Total Circuit Length	0.346 (0.021) ***	0.212 (0.188)
Year	0.022 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-35.931 (4.639) ***	-22.763 (3.492) ***
Ratcheted Max Demand	0.076 (0.033) *	0.808 (0.145) ***
Number of Connections	0.48 (0.035) ***	0.487 (0.237) *
Total Circuit Length	0.347 (0.018) ***	0.22 (0.19)
Year	0.022 (0.002) ***	0.014 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-31.93 (5.654) ***	-32 (4.067) ***
Total Circuit Length	0.257 (0.026) ***	0.061 (0.191)
Number of Connections	0.538 (0.015) ***	0.931 (0.219) ***
Reliability (Class B)	0.02 (0.014)	0.012 (0.011)
Reliability (Class C)	0.062 (0.012) ***	0.039 (0.008) ***
Year	0.019 (0.003) ***	0.019 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-24.131 (5.724) ***	-19.888 (4.301) ***
Ratcheted Max Demand	0.124 (0.071)	0.798 (0.147) ***
Total Circuit Length	0.317 (0.03) ***	0.27 (0.196)
Total Capacity	0.466 (0.093) ***	0.198 (0.119)
Year	0.017 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-31.316 (5.371) ***	-23.234 (3.582) ***
Ratcheted Max Demand	0.476 (0.017) ***	0.927 (0.13) ***
Total Circuit Length	0.424 (0.019) ***	0.347 (0.198)
Year	0.021 (0.003) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-26.017 (4.51) ***	-31.542 (3.398) ***
Number of Connections	0.519 (0.024) ***	0.761 (0.213) ***
Overhead Line Capacity	0.158 (0.007) ***	0.313 (0.039) ***
Underground Cable Capacity	0.159 (0.018) ***	0.048 (0.03)
Year	0.017 (0.002) ***	0.018 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-13.251 (5.23) *	-23.335 (3.566) ***
Ratcheted Max Demand	0.304 (0.034) ***	0.803 (0.131) ***
Overhead Line Capacity	0.189 (0.007) ***	0.302 (0.039) ***
Underground Cable Capacity	0.302 (0.025) ***	0.023 (0.026)
Year	0.012 (0.003) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

Non-Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-23.563 (5.472) ***	-22.798 (3.759) ***
Number of Connections	0.479 (0.022) ***	0.488 (0.184) **
Total Circuit Length	0.503 (0.026) ***	0.615 (0.194) **
Year	0.016 (0.003) ***	0.015 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-9.434 (7.185)	-15.718 (4.696) ***
Volumes Carried	0.314 (0.091) ***	0.294 (0.126) *
Number of Connections	0.048 (0.062)	-0.024 (0.239)
Total Capacity	0.485 (0.111) ***	0.34 (0.12) **
Year	0.01 (0.004) **	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-18.875 (5.882) **	-16.323 (4.356) ***
Volumes Carried	-0.039 (0.139)	0.241 (0.123)
Ratcheted Max Demand	0.268 (0.119) *	0.417 (0.136) **
Number of Connections	0.286 (0.059) ***	-0.129 (0.227)
Total Circuit Length	0.441 (0.049) ***	0.544 (0.191) **
Year	0.014 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-19.449 (5.609) ***	-12.314 (4.344) **
Ratcheted Max Demand	0.238 (0.066) ***	0.586 (0.126) ***
Number of Connections	0.282 (0.055) ***	-0.009 (0.21)
Total Circuit Length	0.433 (0.032) ***	0.555 (0.189) **
Year	0.014 (0.003) ***	0.011 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-11.739 (6.501)	-17.084 (3.942) ***
Total Circuit Length	0.44 (0.03) ***	0.512 (0.203) *
Number of Connections	0.443 (0.027) ***	0.336 (0.192)
Reliability (Class B)	0.062 (0.016) ***	0.046 (0.012) ***
Reliability (Class C)	0.03 (0.019)	-0.002 (0.01)
Year	0.009 (0.003) **	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-9.39 (5.808)	-8.575 (4.456)
Ratcheted Max Demand	0.234 (0.079) **	0.388 (0.138) **
Total Circuit Length	0.337 (0.035) ***	0.472 (0.186) *
Total Capacity	0.366 (0.096) ***	0.252 (0.108) *
Year	0.01 (0.003) ***	0.009 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-14.989 (5.607) **	-12.279 (4.138) **
Ratcheted Max Demand	0.518 (0.025) ***	0.584 (0.114) ***
Total Circuit Length	0.404 (0.034) ***	0.553 (0.179) **
Year	0.013 (0.003) ***	0.011 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-0.042 (4.155)	-4.445 (4.853)
Number of Connections	0.167 (0.039) ***	0.324 (0.152) *
Overhead Line Capacity	0.374 (0.014) ***	0.21 (0.06) ***
Underground Cable Capacity	0.331 (0.026) ***	0.269 (0.049) ***
Year	0.005 (0.002) *	0.007 (0.003) *
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	3.532 (3.686)	-0.602 (4.724)
Ratcheted Max Demand	0.139 (0.037) ***	0.472 (0.113) ***
Overhead Line Capacity	0.353 (0.017) ***	0.221 (0.056) ***
Underground Cable Capacity	0.354 (0.023) ***	0.194 (0.057) ***
Year	0.003 (0.002)	0.006 (0.002) *
EDB Fixed Effects	No	Yes

Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-23.563 (5.472) ***	-22.798 (3.759) ***
Number of Connections	0.479 (0.022) ***	0.488 (0.184) **
Total Circuit Length	0.503 (0.026) ***	0.615 (0.194) **
Year	0.016 (0.003) ***	0.015 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-9.434 (7.185)	-15.718 (4.696) ***
Volumes Carried	0.314 (0.091) ***	0.294 (0.126) *
Number of Connections	0.048 (0.062)	-0.024 (0.239)
Total Capacity	0.485 (0.111) ***	0.34 (0.12) **
Year	0.01 (0.004) **	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-18.875 (5.882) **	-16.323 (4.356) ***
Volumes Carried	-0.039 (0.139)	0.241 (0.123)
Ratcheted Max Demand	0.268 (0.119) *	0.417 (0.136) **
Number of Connections	0.286 (0.059) ***	-0.129 (0.227)
Total Circuit Length	0.441 (0.049) ***	0.544 (0.191) **
Year	0.014 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-19.449 (5.609) ***	-12.314 (4.344) **
Ratcheted Max Demand	0.238 (0.066) ***	0.586 (0.126) ***
Number of Connections	0.282 (0.055) ***	-0.009 (0.21)
Total Circuit Length	0.433 (0.032) ***	0.555 (0.189) **
Year	0.014 (0.003) ***	0.011 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-11.739 (6.501)	-17.084 (3.942) ***
Total Circuit Length	0.44 (0.03) ***	0.512 (0.203) *
Number of Connections	0.443 (0.027) ***	0.336 (0.192)
Reliability (Class B)	0.062 (0.016) ***	0.046 (0.012) ***
Reliability (Class C)	0.03 (0.019)	-0.002 (0.01)
Year	0.009 (0.003) **	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-9.39 (5.808)	-8.575 (4.456)
Ratcheted Max Demand	0.234 (0.079) **	0.388 (0.138) **
Total Circuit Length	0.337 (0.035) ***	0.472 (0.186) *
Total Capacity	0.366 (0.096) ***	0.252 (0.108) *
Year	0.01 (0.003) ***	0.009 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-14.989 (5.607) **	-12.279 (4.138) **
Ratcheted Max Demand	0.518 (0.025) ***	0.584 (0.114) ***
Total Circuit Length	0.404 (0.034) ***	0.553 (0.179) **
Year	0.013 (0.003) ***	0.011 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-0.042 (4.155)	-4.445 (4.853)
Number of Connections	0.167 (0.039) ***	0.324 (0.152) *
Overhead Line Capacity	0.374 (0.014) ***	0.21 (0.06) ***
Underground Cable Capacity	0.331 (0.026) ***	0.269 (0.049) ***
Year	0.005 (0.002) *	0.007 (0.003) *
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	3.532 (3.686)	-0.602 (4.724)
Ratcheted Max Demand	0.139 (0.037) ***	0.472 (0.113) ***
Overhead Line Capacity	0.353 (0.017) ***	0.221 (0.056) ***
Underground Cable Capacity	0.354 (0.023) ***	0.194 (0.057) ***
Year	0.003 (0.002)	0.006 (0.002) *
EDB Fixed Effects	No	Yes

C.1.2. Total Expenditure

All EDBs

	Model 1	Model 1 (FE)
Intercept	-27.276 (3.829) ***	-29.176 (2.591) ***
Number of Connections	0.563 (0.014) ***	0.32 (0.137) *
Total Circuit Length	0.408 (0.013) ***	0.264 (0.117) *
Year	0.017 (0.002) ***	0.02 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-8.647 (5.374)	-23.624 (4.126) ***
Volumes Carried	-0.088 (0.072)	0.414 (0.197) *
Number of Connections	0.278 (0.037) ***	-0.19 (0.18)
Total Capacity	0.722 (0.065) ***	0.236 (0.114) *
Year	0.009 (0.003) ***	0.019 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-22.573 (3.727) ***	-22.153 (3.262) ***
Volumes Carried	-0.125 (0.068)	0.323 (0.19)
Ratcheted Max Demand	0.376 (0.062) ***	0.469 (0.126) ***
Number of Connections	0.299 (0.026) ***	-0.279 (0.201)
Total Circuit Length	0.423 (0.012) ***	0.373 (0.113) **
Year	0.016 (0.002) ***	0.017 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-23.825 (3.553) ***	-19.203 (2.55) ***
Ratcheted Max Demand	0.274 (0.027) ***	0.681 (0.109) ***
Number of Connections	0.292 (0.027) ***	-0.137 (0.165)
Total Circuit Length	0.405 (0.011) ***	0.384 (0.114) ***
Year	0.016 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-24.358 (4.243) ***	-27.429 (2.539) ***
Total Circuit Length	0.38 (0.019) ***	0.26 (0.118) *
Number of Connections	0.564 (0.014) ***	0.296 (0.142) *
Reliability (Class B)	0.016 (0.012)	0.009 (0.008)
Reliability (Class C)	0.007 (0.011)	0.008 (0.006)
Year	0.016 (0.002) ***	0.019 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-17.086 (4.089) ***	-16.923 (3.101) ***
Ratcheted Max Demand	0.324 (0.052) ***	0.565 (0.123) ***
Total Circuit Length	0.394 (0.017) ***	0.299 (0.11) **
Total Capacity	0.255 (0.063) ***	0.127 (0.096)
Year	0.014 (0.002) ***	0.014 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-21.019 (3.906) ***	-19.071 (2.526) ***
Ratcheted Max Demand	0.517 (0.012) ***	0.648 (0.087) ***
Total Circuit Length	0.452 (0.011) ***	0.348 (0.109) **
Year	0.016 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-16.046 (4.022) ***	-23.847 (3.297) ***
Number of Connections	0.56 (0.031) ***	0.123 (0.136)
Overhead Line Capacity	0.169 (0.006) ***	0.137 (0.028) ***
Underground Cable Capacity	0.162 (0.022) ***	0.093 (0.023) ***
Year	0.012 (0.002) ***	0.019 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-7.772 (4.355)	-17.565 (2.924) ***
Ratcheted Max Demand	0.489 (0.031) ***	0.547 (0.104) ***
Overhead Line Capacity	0.184 (0.005) ***	0.113 (0.029) ***
Underground Cable Capacity	0.198 (0.022) ***	0.052 (0.026) *
Year	0.01 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

Non-Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-23.563 (5.472) ***	-22.798 (3.759) ***
Number of Connections	0.479 (0.022) ***	0.488 (0.184) **
Total Circuit Length	0.503 (0.026) ***	0.615 (0.194) **
Year	0.016 (0.003) ***	0.015 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-9.434 (7.185)	-15.718 (4.696) ***
Volumes Carried	0.314 (0.091) ***	0.294 (0.126) *
Number of Connections	0.048 (0.062)	-0.024 (0.239)
Total Capacity	0.485 (0.111) ***	0.34 (0.12) **
Year	0.01 (0.004) **	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-18.875 (5.882) **	-16.323 (4.356) ***
Volumes Carried	-0.039 (0.139)	0.241 (0.123)
Ratcheted Max Demand	0.268 (0.119) *	0.417 (0.136) **
Number of Connections	0.286 (0.059) ***	-0.129 (0.227)
Total Circuit Length	0.441 (0.049) ***	0.544 (0.191) **
Year	0.014 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-19.449 (5.609) ***	-12.314 (4.344) **
Ratcheted Max Demand	0.238 (0.066) ***	0.586 (0.126) ***
Number of Connections	0.282 (0.055) ***	-0.009 (0.21)
Total Circuit Length	0.433 (0.032) ***	0.555 (0.189) **
Year	0.014 (0.003) ***	0.011 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-11.739 (6.501)	-17.084 (3.942) ***
Total Circuit Length	0.44 (0.03) ***	0.512 (0.203) *
Number of Connections	0.443 (0.027) ***	0.336 (0.192)
Reliability (Class B)	0.062 (0.016) ***	0.046 (0.012) ***
Reliability (Class C)	0.03 (0.019)	-0.002 (0.01)
Year	0.009 (0.003) **	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-9.39 (5.808)	-8.575 (4.456)
Ratcheted Max Demand	0.234 (0.079) **	0.388 (0.138) **
Total Circuit Length	0.337 (0.035) ***	0.472 (0.186) *
Total Capacity	0.366 (0.096) ***	0.252 (0.108) *
Year	0.01 (0.003) ***	0.009 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-14.989 (5.607) **	-12.279 (4.138) **
Ratcheted Max Demand	0.518 (0.025) ***	0.584 (0.114) ***
Total Circuit Length	0.404 (0.034) ***	0.553 (0.179) **
Year	0.013 (0.003) ***	0.011 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-0.042 (4.155)	-4.445 (4.853)
Number of Connections	0.167 (0.039) ***	0.324 (0.152) *
Overhead Line Capacity	0.374 (0.014) ***	0.21 (0.06) ***
Underground Cable Capacity	0.331 (0.026) ***	0.269 (0.049) ***
Year	0.005 (0.002) *	0.007 (0.003) *
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	3.532 (3.686)	-0.602 (4.724)
Ratcheted Max Demand	0.139 (0.037) ***	0.472 (0.113) ***
Overhead Line Capacity	0.353 (0.017) ***	0.221 (0.056) ***
Underground Cable Capacity	0.354 (0.023) ***	0.194 (0.057) ***
Year	0.003 (0.002)	0.006 (0.002) *
EDB Fixed Effects	No	Yes

Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-23.563 (5.472) ***	-22.798 (3.759) ***
Number of Connections	0.479 (0.022) ***	0.488 (0.184) **
Total Circuit Length	0.503 (0.026) ***	0.615 (0.194) **
Year	0.016 (0.003) ***	0.015 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-9.434 (7.185)	-15.718 (4.696) ***
Volumes Carried	0.314 (0.091) ***	0.294 (0.126) *
Number of Connections	0.048 (0.062)	-0.024 (0.239)
Total Capacity	0.485 (0.111) ***	0.34 (0.12) **
Year	0.01 (0.004) **	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-18.875 (5.882) **	-16.323 (4.356) ***
Volumes Carried	-0.039 (0.139)	0.241 (0.123)
Ratcheted Max Demand	0.268 (0.119) *	0.417 (0.136) **
Number of Connections	0.286 (0.059) ***	-0.129 (0.227)
Total Circuit Length	0.441 (0.049) ***	0.544 (0.191) **
Year	0.014 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-19.449 (5.609) ***	-12.314 (4.344) **
Ratcheted Max Demand	0.238 (0.066) ***	0.586 (0.126) ***
Number of Connections	0.282 (0.055) ***	-0.009 (0.21)
Total Circuit Length	0.433 (0.032) ***	0.555 (0.189) **
Year	0.014 (0.003) ***	0.011 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-11.739 (6.501)	-17.084 (3.942) ***
Total Circuit Length	0.44 (0.03) ***	0.512 (0.203) *
Number of Connections	0.443 (0.027) ***	0.336 (0.192)
Reliability (Class B)	0.062 (0.016) ***	0.046 (0.012) ***
Reliability (Class C)	0.03 (0.019)	-0.002 (0.01)
Year	0.009 (0.003) **	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-9.39 (5.808)	-8.575 (4.456)
Ratcheted Max Demand	0.234 (0.079) **	0.388 (0.138) **
Total Circuit Length	0.337 (0.035) ***	0.472 (0.186) *
Total Capacity	0.366 (0.096) ***	0.252 (0.108) *
Year	0.01 (0.003) ***	0.009 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-14.989 (5.607) **	-12.279 (4.138) **
Ratcheted Max Demand	0.518 (0.025) ***	0.584 (0.114) ***
Total Circuit Length	0.404 (0.034) ***	0.553 (0.179) **
Year	0.013 (0.003) ***	0.011 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-0.042 (4.155)	-4.445 (4.853)
Number of Connections	0.167 (0.039) ***	0.324 (0.152) *
Overhead Line Capacity	0.374 (0.014) ***	0.21 (0.06) ***
Underground Cable Capacity	0.331 (0.026) ***	0.269 (0.049) ***
Year	0.005 (0.002) *	0.007 (0.003) *
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	3.532 (3.686)	-0.602 (4.724)
Ratcheted Max Demand	0.139 (0.037) ***	0.472 (0.113) ***
Overhead Line Capacity	0.353 (0.017) ***	0.221 (0.056) ***
Underground Cable Capacity	0.354 (0.023) ***	0.194 (0.057) ***
Year	0.003 (0.002)	0.006 (0.002) *
EDB Fixed Effects	No	Yes

C.2. Translog Model Results

C.2.1. Operating Expenditure

All EDBs

	Model 1	Model 1 (FE)
Intercept	-34.728 (4.719) ***	-42.313 (8.897) ***
Number of Connections	0.231 (0.173)	2.282 (1.319)
Total Circuit Length	0.334 (0.166) *	-0.098 (1.39)
Number of Connections^2	-0.058 (0.019) **	0.373 (0.115) **
Total Circuit Length^2	-0.125 (0.023) ***	0.742 (0.119) ***
Number of Connections x Total Circuit Length	0.191 (0.042) ***	-1.113 (0.268) ***
Year	0.022 (0.002) ***	0.02 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-33.504 (6.262) ***	3.599 (10.345)
Volumes Carried	1.142 (1.078)	0.568 (0.94)
Number of Connections	5.851 (1.176) ***	-10.437 (3.204) **
Total Capacity	-4.09 (0.815) ***	7.197 (2.009) ***
Volumes Carried^2	1.829 (0.305) ***	0.462 (0.347)
Number of Connections^2	-0.293 (0.109) **	0.802 (0.252) **
Total Capacity^2	0.441 (0.308)	1.342 (0.321) ***
Volumes Carried x Number of Connections	-1.107 (0.266) ***	0.293 (0.32)
Volumes Carried x Total Capacity	-2.124 (0.558) ***	-1.499 (0.554) **
Total Capacity x Number of Connections	1.245 (0.172) ***	-1.306 (0.371) ***
Year	0.012 (0.003) ***	0.02 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-43.455 (6.144) ***	-17.789 (11.999)
Volumes Carried	3.446 (1.836)	-0.275 (1.538)
Ratcheted Max Demand	-2.309 (1.237)	6.319 (2.206) **
Number of Connections	-0.947 (1.38)	-7.238 (2.872) *
Total Circuit Length	1.6 (0.923)	2.326 (1.888)
Volumes Carried^2	-0.006 (0.37)	0.546 (0.588)
Ratcheted Max Demand^2	-0.143 (0.302)	1.016 (0.374) **
Number of Connections^2	0.12 (0.124)	0.729 (0.272) **
Total Circuit Length^2	-0.025 (0.038)	0.577 (0.114) ***
Volumes Carried x Ratcheted Max Demand	0.398 (0.619)	-1.274 (0.925)
Volumes Carried x Number of Connections	0.211 (0.348)	0.976 (0.338) **
Volumes Carried x Total Circuit Length	-0.874 (0.189) ***	-1.248 (0.207) ***
Ratcheted Max Demand x Number of Connections	-0.581 (0.257) *	-1.556 (0.433) ***
Ratcheted Max Demand x Total Circuit Length	0.868 (0.256) ***	1.049 (0.327) **
Number of Connections x Total Circuit Length	0.04 (0.157)	-0.818 (0.386) *
Year	0.024 (0.002) ***	0.022 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-40.939 (6.287) ***	-3.19 (11.457)
Ratcheted Max Demand	-0.582 (0.823)	6.581 (2.178) **
Number of Connections	2.24 (1.081) *	-6.744 (2.531) **
Total Circuit Length	-0.053 (0.58)	0.299 (2.232)
Ratcheted Max Demand^2	0.087 (0.078)	0.461 (0.171) **
Number of Connections^2	-0.179 (0.095)	0.988 (0.281) ***
Total Circuit Length^2	-0.144 (0.026) ***	0.614 (0.118) ***
Ratcheted Max Demand x Number of Connections	-0.024 (0.128)	-1.096 (0.37) **
Ratcheted Max Demand x Total Circuit Length	0.024 (0.109)	0.145 (0.362)
Number of Connections x Total Circuit Length	0.247 (0.107) *	-1.013 (0.449) *
Year	0.021 (0.002) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-32.187 (5.92) ***	-36.479 (7.535) ***
Total Circuit Length	-0.613 (0.257) *	-0.434 (1.319)
Number of Connections	0.269 (0.176)	1.359 (1.091)
Reliability (Class B)	0.367 (0.085) ***	0.371 (0.069) ***
Reliability (Class C)	0.442 (0.124) ***	0.053 (0.084)
Total Circuit Length^2	-0.179 (0.041) ***	0.681 (0.121) ***
Number of Connections^2	-0.014 (0.024)	0.493 (0.104) ***
Reliability (Class B)^2	0.006 (0.004)	-0.001 (0.002)
Reliability (Class C)^2	0.003 (0.007)	-0.002 (0.005)
Number of Connections x Reliability (Class B)	-0.037 (0.02)	-0.059 (0.015) ***
Number of Connections x Reliability (Class C)	-0.036 (0.018) *	0 (0.012)
Reliability (Class B) x Reliability (Class C)	-0.039 (0.013) **	-0.03 (0.01) **
Total Circuit Length x Number of Connections	0.2 (0.046) ***	-1.222 (0.262) ***
Total Circuit Length x Reliability (Class B)	0.06 (0.031) *	0.094 (0.02) ***
Total Circuit Length x Reliability (Class C)	0.053 (0.033)	0.061 (0.023) **
Year	0.019 (0.003) ***	0.019 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-23.82 (5.356) ***	-4.801 (5.335)
Ratcheted Max Demand	3.756 (0.681) ***	4.865 (1.681) **
Total Circuit Length	1.503 (0.272) ***	-4.305 (0.949) ***
Total Capacity	-4.949 (0.838) ***	-3.226 (1.592) *
Ratcheted Max Demand^2	0.584 (0.269) *	0.677 (0.219) **
Total Circuit Length^2	-0.281 (0.035) ***	0.257 (0.11) *
Total Capacity^2	0.189 (0.422)	0.13 (0.257)
Ratcheted Max Demand x Total Circuit Length	-0.424 (0.195) *	-0.71 (0.255) **
Ratcheted Max Demand x Total Capacity	-0.939 (0.676)	-0.792 (0.438)
Total Circuit Length x Total Capacity	0.912 (0.223) ***	0.681 (0.239) **
Year	0.018 (0.003) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-31.512 (5.061) ***	-8.274 (5.053)
Ratcheted Max Demand	-0.76 (0.219) ***	2.482 (1.055) *
Total Circuit Length	1.354 (0.216) ***	-4.996 (0.759) ***
Ratcheted Max Demand^2	-0.058 (0.021) **	0.173 (0.104)
Total Circuit Length^2	-0.125 (0.028) ***	0.452 (0.088) ***
Ratcheted Max Demand x Total Circuit Length	0.221 (0.05) ***	-0.398 (0.192) *
Year	0.02 (0.003) ***	0.017 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-18.445 (4.691) ***	-42.779 (17.361) *
Number of Connections	0.105 (0.56)	1.564 (2.979)
Overhead Line Capacity	0.126 (0.087)	2.451 (1.172) *
Underground Cable Capacity	-0.071 (0.409)	-0.329 (0.916)
Number of Connections^2	-0.056 (0.044)	0.045 (0.154)
Overhead Line Capacity^2	-0.003 (0.008)	-0.003 (0.016)
Underground Cable Capacity^2	-0.016 (0.02)	0.023 (0.028)
Number of Connections x Overhead Line Capacity	0.059 (0.032)	-0.209 (0.148)
Number of Connections x Underground Cable Capacity	0.119 (0.062)	0.013 (0.124)
Overhead Line Capacity x Underground Cable Capacity	-0.071 (0.021) **	0.001 (0.037)
Year	0.015 (0.002) ***	0.018 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-8.864 (4.763)	-28.75 (5.045) ***
Ratcheted Max Demand	0.342 (0.335)	-0.042 (1.009)
Overhead Line Capacity	0.185 (0.105)	0.939 (0.358) **
Underground Cable Capacity	0.013 (0.028)	0.382 (0.387)
Ratcheted Max Demand^2	0.16 (0.068) *	-0.354 (0.166) *
Overhead Line Capacity^2	0.01 (0.006)	-0.03 (0.011) **
Underground Cable Capacity^2	0.092 (0.03) **	-0.106 (0.043) *
Ratcheted Max Demand x Overhead Line Capacity	-0.05 (0.035)	0.116 (0.105)
Ratcheted Max Demand x Underground Cable Capacity	-0.18 (0.096)	0.432 (0.157) **
Overhead Line Capacity x Underground Cable Capacity	-0.163 (0.239)	-0.094 (0.046) *
Year	0.01 (0.002) ***	0.018 (0.002) ***
EDB Fixed Effects	No	Yes

Non-Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-33.047 (5.668) ***	-49.508 (15.812) **
Number of Connections	0.407 (0.245)	3.398 (1.685) *
Total Circuit Length	0.475 (0.152) **	-0.945 (3.012)
Number of Connections^2	-0.07 (0.023) **	0.321 (0.246)
Total Circuit Length^2	-0.148 (0.038) ***	0.766 (0.229) ***
Number of Connections x Total Circuit Length	0.207 (0.062) **	-1.104 (0.608)
Year	0.02 (0.003) ***	0.023 (0.004) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-50.066 (6.666) ***	-3.741 (8.194)
Volumes Carried	4.635 (1.817) *	1.344 (0.796)
Number of Connections	4.477 (1.888) *	-6.402 (2.573) *
Total Capacity	-3.819 (0.946) ***	4.389 (1.655) **
Volumes Carried^2	2.871 (0.364) ***	1.077 (0.265) ***
Number of Connections^2	0.181 (0.232)	0.293 (0.202)
Total Capacity^2	1.082 (0.317) ***	1.63 (0.182) ***
Volumes Carried x Number of Connections	-2.177 (0.439) ***	0.406 (0.259)
Volumes Carried x Total Capacity	-3.014 (0.617) ***	-3.028 (0.328) ***
Total Capacity x Number of Connections	0.995 (0.199) ***	-0.406 (0.317)
Year	0.017 (0.003) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-69.597 (7.633) ***	-42.24 (13.527) **
Volumes Carried	3.688 (1.64) *	-0.725 (1.033)
Ratcheted Max Demand	-3.538 (1.596) *	2.739 (2.093)
Number of Connections	0.857 (1.47)	-1.508 (2.622)
Total Circuit Length	6.35 (1.668) ***	3.697 (2.605)
Volumes Carried^2	0.914 (0.414) *	1.066 (0.592)
Ratcheted Max Demand^2	0.267 (0.33)	0.699 (0.381)
Number of Connections^2	0.886 (0.208) ***	0.493 (0.313)
Total Circuit Length^2	0.269 (0.053) ***	0.577 (0.174) **
Volumes Carried x Ratcheted Max Demand	-0.311 (0.601)	-1.927 (0.867) *
Volumes Carried x Number of Connections	-0.338 (0.385)	0.686 (0.323) *
Volumes Carried x Total Circuit Length	-1.205 (0.193) ***	-1.22 (0.187) ***
Ratcheted Max Demand x Number of Connections	-1.367 (0.331) ***	-0.791 (0.46)
Ratcheted Max Demand x Total Circuit Length	2.072 (0.375) ***	1.4 (0.408) ***
Number of Connections x Total Circuit Length	-1.217 (0.292) ***	-1.131 (0.57) *
Year	0.023 (0.002) ***	0.021 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-60.185 (9.439) ***	-41.906 (16.081) **
Ratcheted Max Demand	-1.905 (0.889) *	0.632 (2.419)
Number of Connections	1.328 (2.076)	1.139 (2.787)
Total Circuit Length	7.164 (1.599) ***	3.893 (3.459)
Ratcheted Max Demand^2	0.376 (0.079) ***	-0.265 (0.158)
Number of Connections^2	0.819 (0.235) ***	0.764 (0.404)
Total Circuit Length^2	0.018 (0.052)	0.754 (0.189) ***
Ratcheted Max Demand x Number of Connections	-1.335 (0.251) ***	-0.251 (0.515)
Ratcheted Max Demand x Total Circuit Length	1.48 (0.288) ***	0.685 (0.577)
Number of Connections x Total Circuit Length	-1.364 (0.277) ***	-1.835 (0.739) *
Year	0.019 (0.002) ***	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-37.762 (6.468) ***	-49.288 (12.547) ***
Total Circuit Length	0.666 (0.361)	-2.173 (2.834)
Number of Connections	0.304 (0.322)	2.721 (1.356) *
Reliability (Class B)	0.069 (0.129)	0.382 (0.08) ***
Reliability (Class C)	-0.078 (0.149)	0.059 (0.097)
Total Circuit Length^2	-0.073 (0.065)	0.77 (0.217) ***
Number of Connections^2	-0.092 (0.03) **	0.44 (0.219) *
Reliability (Class B)^2	0.003 (0.005)	0 (0.002)
Reliability (Class C)^2	0.02 (0.01) *	-0.011 (0.006) *
Number of Connections x Reliability (Class B)	0.001 (0.026)	-0.057 (0.016) ***
Number of Connections x Reliability (Class C)	0.037 (0.022)	-0.001 (0.014)
Reliability (Class B) x Reliability (Class C)	-0.012 (0.02)	-0.028 (0.013) *
Total Circuit Length x Number of Connections	0.204 (0.084) *	-1.256 (0.561) *
Total Circuit Length x Reliability (Class B)	0.001 (0.048)	0.084 (0.026) **
Total Circuit Length x Reliability (Class C)	-0.091 (0.043) *	0.09 (0.03) **
Year	0.023 (0.003) ***	0.026 (0.004) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-17.201 (6.9) *	-0.185 (6.357)
Ratcheted Max Demand	5.77 (0.823) ***	4.822 (2.117) *
Total Circuit Length	0.246 (0.348)	-4.293 (0.917) ***
Total Capacity	-5.221 (0.943) ***	-2.888 (1.829)
Ratcheted Max Demand^2	1.69 (0.425) ***	0.907 (0.252) ***
Total Circuit Length^2	-0.053 (0.056)	0.194 (0.101)
Total Capacity^2	1.491 (0.639) *	1.113 (0.357) **
Ratcheted Max Demand x Total Circuit Length	-0.342 (0.248)	0.133 (0.308)
Ratcheted Max Demand x Total Capacity	-3.221 (1.039) **	-2.281 (0.565) ***
Total Circuit Length x Total Capacity	0.433 (0.308)	0.108 (0.319)
Year	0.015 (0.003) ***	0.013 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-29.363 (6.388) ***	-7.966 (5.677)
Ratcheted Max Demand	0.668 (0.351)	2.917 (1.124) *
Total Circuit Length	0.195 (0.313)	-4.938 (0.67) ***
Ratcheted Max Demand^2	0.019 (0.029)	-0.149 (0.104)
Total Circuit Length^2	0.028 (0.041)	0.322 (0.082) ***
Ratcheted Max Demand x Total Circuit Length	-0.041 (0.074)	-0.029 (0.192)
Year	0.02 (0.003) ***	0.017 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-19.116 (5.449) ***	-21.667 (28.026)
Number of Connections	0.33 (0.712)	-0.11 (4.959)
Overhead Line Capacity	0.118 (0.099)	0.796 (1.979)
Underground Cable Capacity	0.512 (0.563)	-1.226 (1.359)
Number of Connections^2	0.013 (0.044)	0.137 (0.208)
Overhead Line Capacity^2	-0.003 (0.01)	0.011 (0.025)
Underground Cable Capacity^2	0.072 (0.021) ***	0.104 (0.029) ***
Number of Connections x Overhead Line Capacity	0.039 (0.049)	-0.182 (0.231)
Number of Connections x Underground Cable Capacity	-0.078 (0.062)	-0.15 (0.18)
Overhead Line Capacity x Underground Cable Capacity	-0.045 (0.042)	0.154 (0.063) *
Year	0.013 (0.003) ***	0.019 (0.005) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	4.45 (5.585)	-19.512 (6.519) **
Ratcheted Max Demand	1.936 (0.473) ***	3.905 (1.178) **
Overhead Line Capacity	-0.124 (0.146)	-0.284 (0.552)
Underground Cable Capacity	-1.285 (0.414) **	-1.689 (0.595) **
Ratcheted Max Demand^2	0.323 (0.081) ***	-0.555 (0.191) **
Overhead Line Capacity^2	0.029 (0.007) ***	-0.005 (0.014)
Underground Cable Capacity^2	0.236 (0.035) ***	-0.02 (0.045)
Ratcheted Max Demand x Overhead Line Capacity	-0.169 (0.045) ***	0.033 (0.112)
Ratcheted Max Demand x Underground Cable Capacity	-0.484 (0.116) ***	0.309 (0.165)
Overhead Line Capacity x Underground Cable Capacity	0.086 (0.038) *	0.059 (0.06)
Year	0.004 (0.003)	0.015 (0.003) ***
EDB Fixed Effects	No	Yes

Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-36.958 (7.312) ***	-21.733 (18.96)
Number of Connections	1.089 (0.662)	-0.764 (3.427)
Total Circuit Length	-1.329 (0.734)	-0.148 (3.99)
Number of Connections^2	-0.331 (0.069) ***	0.427 (0.204) *
Total Circuit Length^2	-0.38 (0.064) ***	0.626 (0.503)
Number of Connections x Total Circuit Length	0.77 (0.117) ***	-0.887 (0.513)
Year	0.024 (0.004) ***	0.018 (0.004) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-44.455 (12.764) ***	66.865 (25.124) **
Volumes Carried	5.847 (2.825) *	3.016 (2.882)
Number of Connections	3.317 (3)	-28.476 (5.898) ***
Total Capacity	-8.37 (2.89) **	13.683 (3.111) ***
Volumes Carried^2	2.182 (0.916) *	0.096 (0.443)
Number of Connections^2	-0.24 (0.3)	2.164 (0.532) ***
Total Capacity^2	2.103 (1.058) *	1.359 (0.461) **
Volumes Carried x Number of Connections	-0.676 (0.547)	-0.092 (0.695)
Volumes Carried x Total Capacity	-4.329 (1.811) *	-0.56 (0.837)
Total Capacity x Number of Connections	1.023 (0.589)	-2.522 (0.648) ***
Year	0.023 (0.005) ***	0.02 (0.005) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-112.131 (23.278) ***	64.179 (26.585) *
Volumes Carried	0.685 (7.882)	12.365 (3.363) ***
Ratcheted Max Demand	-20.023 (6.26) **	15.596 (4.917) **
Number of Connections	8.425 (6.241)	-22.456 (5.78) ***
Total Circuit Length	16.794 (5.603) **	-11.984 (5.812) *
Volumes Carried^2	3.868 (1.851) *	5.793 (1.222) ***
Ratcheted Max Demand^2	2.767 (1.014) **	4.605 (0.635) ***
Number of Connections^2	-0.45 (0.507)	1.565 (0.491) **
Total Circuit Length^2	-1.886 (0.348) ***	1.289 (0.558) *
Volumes Carried x Ratcheted Max Demand	-8.374 (2.414) ***	-8.193 (1.714) ***
Volumes Carried x Number of Connections	-1.699 (1.094)	-1.597 (0.666) *
Volumes Carried x Total Circuit Length	0.84 (1.55)	-3.67 (1.076) ***
Ratcheted Max Demand x Number of Connections	2.692 (1.055) *	-1.562 (0.799)
Ratcheted Max Demand x Total Circuit Length	2.331 (1.006) *	1.137 (0.901)
Number of Connections x Total Circuit Length	-0.089 (0.753)	0.91 (0.621)
Year	0.028 (0.004) ***	0.019 (0.005) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-74.722 (20.741) ***	97.524 (26.921) ***
Ratcheted Max Demand	-11.208 (5.41) *	26.368 (4.678) ***
Number of Connections	-4.583 (5.111)	-24.583 (6.166) ***
Total Circuit Length	21.041 (4.93) ***	-12.782 (5.542) *
Ratcheted Max Demand^2	-0.822 (0.489)	1.854 (0.394) ***
Number of Connections^2	0.824 (0.464)	1.62 (0.487) **
Total Circuit Length^2	-1.399 (0.244) ***	1.004 (0.517)
Ratcheted Max Demand x Number of Connections	-0.618 (0.889)	-2.758 (0.689) ***
Ratcheted Max Demand x Total Circuit Length	3.076 (0.646) ***	-1.79 (0.461) ***
Number of Connections x Total Circuit Length	-1.13 (0.414) **	0.529 (0.642)
Year	0.025 (0.004) ***	0.015 (0.005) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-34.536 (10.52) **	-10.718 (22.466)
Total Circuit Length	-1.184 (0.892)	0.261 (4.59)
Number of Connections	0.804 (0.813)	-1.578 (3.821)
Reliability (Class B)	1.045 (0.245) ***	0.569 (0.335)
Reliability (Class C)	0.412 (0.282)	-0.215 (0.221)
Total Circuit Length^2	-0.515 (0.085) ***	0.839 (0.482)
Number of Connections^2	-0.134 (0.099)	0.801 (0.232) ***
Reliability (Class B)^2	-0.019 (0.015)	-0.01 (0.014)
Reliability (Class C)^2	-0.01 (0.017)	0.007 (0.011)
Number of Connections x Reliability (Class B)	-0.056 (0.051)	-0.113 (0.041) **
Number of Connections x Reliability (Class C)	-0.14 (0.07) *	0.01 (0.045)
Reliability (Class B) x Reliability (Class C)	-0.009 (0.026)	-0.022 (0.018)
Total Circuit Length x Number of Connections	0.646 (0.137) ***	-1.552 (0.524) **
Total Circuit Length x Reliability (Class B)	0.03 (0.068)	0.154 (0.075) *
Total Circuit Length x Reliability (Class C)	0.188 (0.077) *	0.032 (0.05)
Year	0.018 (0.005) ***	0.012 (0.005) *
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-31.63 (8.947) ***	35.746 (16.755) *
Ratcheted Max Demand	7.5 (3.57) *	6.838 (3.682)
Total Circuit Length	5.615 (1.608) ***	-19.382 (5.413) ***
Total Capacity	-13.561 (3.404) ***	2.815 (3.793)
Ratcheted Max Demand^2	1.382 (0.657) *	1.052 (0.594)
Total Circuit Length^2	-0.901 (0.132) ***	1.783 (0.469) ***
Total Capacity^2	1.011 (0.783)	-0.058 (0.478)
Ratcheted Max Demand x Total Circuit Length	-0.287 (0.453)	-1.664 (0.579) **
Ratcheted Max Demand x Total Capacity	-2.949 (1.362) *	-0.378 (0.928)
Total Circuit Length x Total Capacity	1.859 (0.463) ***	-0.063 (0.594)
Year	0.022 (0.004) ***	0.014 (0.004) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-55.302 (7.394) ***	14.722 (13.869)
Ratcheted Max Demand	-7.094 (1.077) ***	7.232 (1.734) ***
Total Circuit Length	9.899 (1.524) ***	-13.326 (4.067) **
Ratcheted Max Demand^2	-0.472 (0.083) ***	0.595 (0.162) ***
Total Circuit Length^2	-0.987 (0.148) ***	1.312 (0.33) ***
Ratcheted Max Demand x Total Circuit Length	1.459 (0.216) ***	-1.491 (0.33) ***
Year	0.022 (0.004) ***	0.017 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-6.567 (10.919)	-130.281 (40.896) **
Number of Connections	-9.707 (2.9) ***	20.762 (9.549) *
Overhead Line Capacity	5.495 (1.013) ***	4.556 (2.963)
Underground Cable Capacity	2.543 (1.933)	-6.453 (3.03) *
Number of Connections^2	1.175 (0.283) ***	-0.819 (0.599)
Overhead Line Capacity^2	0.024 (0.038)	0.371 (0.131) **
Underground Cable Capacity^2	0.155 (0.105)	-0.35 (0.139) *
Number of Connections x Overhead Line Capacity	-0.854 (0.199) ***	-1.068 (0.382) **
Number of Connections x Underground Cable Capacity	-0.875 (0.328) **	1.101 (0.509) *
Overhead Line Capacity x Underground Cable Capacity	0.476 (0.105) ***	-0.018 (0.141)
Year	0.016 (0.004) ***	0.017 (0.005) **
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-18.724 (7.006) **	-41.385 (10.123) ***
Ratcheted Max Demand	-4.866 (1.188) ***	5.621 (2.649) *
Overhead Line Capacity	3.401 (0.877) ***	0.421 (1.588)
Underground Cable Capacity	1.767 (0.583) **	-0.484 (1.297)
Ratcheted Max Demand^2	-0.471 (0.237) *	-0.32 (0.4)
Overhead Line Capacity^2	-0.251 (0.064) ***	0.168 (0.091)
Underground Cable Capacity^2	-0.087 (0.103)	-0.356 (0.108) **
Ratcheted Max Demand x Overhead Line Capacity	0.686 (0.186) ***	-0.862 (0.392) *
Ratcheted Max Demand x Underground Cable Capacity	0.397 (0.303)	0.911 (0.386) *
Overhead Line Capacity x Underground Cable Capacity	-0.207 (0.084) *	0.117 (0.204)
Year	0.01 (0.003) **	0.021 (0.004) ***
EDB Fixed Effects	No	Yes

C.2.2. Total Expenditure

All EDBs

	Model 1	Model 1 (FE)
Intercept	-25.483 (3.851) ***	-28.971 (5.013) ***
Number of Connections	-0.262 (0.162)	-0.741 (0.936)
Total Circuit Length	0.95 (0.175) ***	1.55 (0.881)
Number of Connections^2	0.102 (0.021) ***	0.265 (0.074) ***
Total Circuit Length^2	0.074 (0.017) ***	0.272 (0.077) ***
Number of Connections x Total Circuit Length	-0.164 (0.039) ***	-0.543 (0.163) ***
Year	0.018 (0.002) ***	0.02 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-9.849 (6.477)	-10.14 (10.284)
Volumes Carried	3.306 (1.291) *	0.113 (1.418)
Number of Connections	1.067 (1.35)	-4.083 (2.791)
Total Capacity	-2.814 (0.863) **	2.479 (1.509)
Volumes Carried^2	1.517 (0.289) ***	0.321 (0.308)
Number of Connections^2	0.047 (0.118)	0.284 (0.26)
Total Capacity^2	0.067 (0.286)	0.587 (0.227) *
Volumes Carried x Number of Connections	-1.356 (0.278) ***	0.075 (0.296)
Volumes Carried x Total Capacity	-1.382 (0.535) *	-0.754 (0.567)
Total Capacity x Number of Connections	1.106 (0.18) ***	-0.434 (0.287)
Year	0.008 (0.003) **	0.02 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-21.451 (4.842) ***	-1.821 (8.258)
Volumes Carried	3.865 (1.598) *	1.713 (0.864) *
Ratcheted Max Demand	-0.104 (1.118)	2.955 (1.309) *
Number of Connections	-4.399 (1.076) ***	-4.98 (1.739) **
Total Circuit Length	1.789 (0.7) *	-2.86 (1.575)
Volumes Carried^2	-1.427 (0.344) ***	0.291 (0.319)
Ratcheted Max Demand^2	-0.614 (0.304) *	0.454 (0.191) *
Number of Connections^2	0.447 (0.097) ***	-0.253 (0.211)
Total Circuit Length^2	0.089 (0.032) **	0.05 (0.095)
Volumes Carried x Ratcheted Max Demand	2.253 (0.644) ***	-0.314 (0.489)
Volumes Carried x Number of Connections	0.491 (0.271)	0.486 (0.278)
Volumes Carried x Total Circuit Length	-0.194 (0.197)	-1.034 (0.27) ***
Ratcheted Max Demand x Number of Connections	-1.069 (0.226) ***	-0.268 (0.253)
Ratcheted Max Demand x Total Circuit Length	0.361 (0.226)	-0.245 (0.23)
Number of Connections x Total Circuit Length	-0.318 (0.119) **	0.951 (0.355) **
Year	0.019 (0.002) ***	0.022 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-20.654 (4.933) ***	7.813 (10.237)
Ratcheted Max Demand	2.043 (0.635) **	3.173 (1.274) *
Number of Connections	-1.526 (0.949)	-3.193 (1.785)
Total Circuit Length	0.697 (0.516)	-4.102 (2.988)
Ratcheted Max Demand^2	0.245 (0.052) ***	0.326 (0.106) **
Number of Connections^2	0.229 (0.089) *	-0.184 (0.349)
Total Circuit Length^2	0.043 (0.019) *	0.093 (0.091)
Ratcheted Max Demand x Number of Connections	-0.426 (0.095) ***	0.199 (0.358)
Ratcheted Max Demand x Total Circuit Length	0.038 (0.086)	-0.917 (0.481)
Number of Connections x Total Circuit Length	-0.111 (0.095)	0.697 (0.577)
Year	0.017 (0.002) ***	0.017 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-20.246 (4.612) ***	-30.084 (5.968) ***
Total Circuit Length	0.476 (0.208) *	1.913 (0.897) *
Number of Connections	-0.348 (0.167) *	-0.229 (0.952)
Reliability (Class B)	0.121 (0.079)	0.058 (0.065)
Reliability (Class C)	0.33 (0.128) *	-0.014 (0.08)
Total Circuit Length^2	0.024 (0.028)	0.275 (0.087) **
Number of Connections^2	0.133 (0.023) ***	0.3 (0.08) ***
Reliability (Class B)^2	0.002 (0.002)	-0.005 (0.002) **
Reliability (Class C)^2	0.006 (0.006)	0.002 (0.004)
Number of Connections x Reliability (Class B)	-0.007 (0.023)	-0.013 (0.02)
Number of Connections x Reliability (Class C)	-0.026 (0.017)	0.018 (0.011)
Reliability (Class B) x Reliability (Class C)	-0.035 (0.018)	-0.023 (0.014)
Total Circuit Length x Number of Connections	-0.173 (0.035) ***	-0.701 (0.177) ***
Total Circuit Length x Reliability (Class B)	0.059 (0.022) **	0.072 (0.017) ***
Total Circuit Length x Reliability (Class C)	0.032 (0.028)	0.011 (0.019)
Year	0.014 (0.002) ***	0.018 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-14.533 (3.807) ***	-13.3 (3.713) ***
Ratcheted Max Demand	3.319 (0.414) ***	5.188 (1.456) ***
Total Circuit Length	0.499 (0.179) **	0.167 (0.796)
Total Capacity	-3.348 (0.511) ***	-4.684 (1.375) ***
Ratcheted Max Demand^2	0.687 (0.187) ***	0.766 (0.234) **
Total Circuit Length^2	-0.03 (0.025)	-0.024 (0.088)
Total Capacity^2	0.64 (0.286) *	0.117 (0.206)
Ratcheted Max Demand x Total Circuit Length	-0.227 (0.13)	-0.908 (0.296) **
Ratcheted Max Demand x Total Capacity	-1.29 (0.459) **	-0.738 (0.358) *
Total Circuit Length x Total Capacity	0.254 (0.151)	0.841 (0.262) **
Year	0.014 (0.002) ***	0.014 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-20.751 (3.639) ***	-15.022 (3.554) ***
Ratcheted Max Demand	0.367 (0.153) *	1.426 (0.682) *
Total Circuit Length	0.273 (0.128) *	-1.162 (0.665)
Ratcheted Max Demand^2	0.049 (0.016) **	0.281 (0.115) *
Total Circuit Length^2	0.025 (0.018)	0.217 (0.085) *
Ratcheted Max Demand x Total Circuit Length	-0.043 (0.037)	-0.414 (0.191) *
Year	0.016 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-2.529 (3.671)	-27.478 (10.136) **
Number of Connections	-1.714 (0.537) **	0.784 (1.686)
Overhead Line Capacity	0.395 (0.099) ***	2.412 (0.814) **
Underground Cable Capacity	1.124 (0.384) **	-0.712 (0.531)
Number of Connections^2	0.124 (0.039) **	-0.011 (0.113)
Overhead Line Capacity^2	0.026 (0.007) ***	0.001 (0.01)
Underground Cable Capacity^2	0.047 (0.019) *	0.016 (0.019)
Number of Connections x Overhead Line Capacity	-0.003 (0.03)	-0.184 (0.109)
Number of Connections x Underground Cable Capacity	-0.073 (0.056)	0.137 (0.084)
Overhead Line Capacity x Underground Cable Capacity	-0.081 (0.017) ***	-0.065 (0.028) *
Year	0.009 (0.002) ***	0.015 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-2.657 (3.477)	-20.446 (3.949) ***
Ratcheted Max Demand	0.015 (0.263)	1.132 (0.741)
Overhead Line Capacity	0.226 (0.08) **	1.394 (0.239) ***
Underground Cable Capacity	0.317 (0.187)	0.328 (0.284)
Ratcheted Max Demand^2	0.181 (0.057) **	0.069 (0.214)
Overhead Line Capacity^2	0.025 (0.006) ***	0.007 (0.013)
Underground Cable Capacity^2	0.096 (0.028) ***	-0.018 (0.033)
Ratcheted Max Demand x Overhead Line Capacity	-0.016 (0.029)	-0.231 (0.15)
Ratcheted Max Demand x Underground Cable Capacity	-0.189 (0.083) *	0.142 (0.15)
Overhead Line Capacity x Underground Cable Capacity	-0.048 (0.021) *	-0.061 (0.05)
Year	0.007 (0.002) ***	0.012 (0.002) ***
EDB Fixed Effects	No	Yes

Non-Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-22.087 (4.638) ***	-39.783 (11.089) ***
Number of Connections	-1.632 (0.264) ***	1.669 (1.309)
Total Circuit Length	1.169 (0.152) ***	-0.479 (1.897)
Number of Connections^2	0.088 (0.023) ***	0.048 (0.154)
Total Circuit Length^2	-0.071 (0.041)	0.215 (0.142)
Number of Connections x Total Circuit Length	0.032 (0.07)	-0.285 (0.373)
Year	0.019 (0.002) ***	0.024 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-25.387 (11.279) *	-25.223 (14.192)
Volumes Carried	6.444 (2.523) *	0.02 (0.913)
Number of Connections	-2.582 (3.209)	-1.299 (3.652)
Total Capacity	-1.148 (1.064)	1.829 (2.371)
Volumes Carried^2	2.667 (0.501) ***	1.425 (0.522) **
Number of Connections^2	0.67 (0.308) *	0.172 (0.279)
Total Capacity^2	0.741 (0.46)	1.18 (0.278) ***
Volumes Carried x Number of Connections	-2.458 (0.465) ***	-0.347 (0.245)
Volumes Carried x Total Capacity	-2.394 (0.989) *	-2.311 (0.784) **
Total Capacity x Number of Connections	0.754 (0.236) **	-0.097 (0.437)
Year	0.017 (0.003) ***	0.021 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-41.437 (6.314) ***	-5.502 (12.869)
Volumes Carried	1.787 (1.205)	1.203 (0.818)
Ratcheted Max Demand	-0.037 (1.105)	5.725 (1.782) **
Number of Connections	-2.029 (1.259)	-6.036 (2.247) **
Total Circuit Length	4.318 (1.445) **	-3.827 (2.346)
Volumes Carried^2	0.161 (0.42)	0.404 (0.484)
Ratcheted Max Demand^2	-0.049 (0.264)	0.205 (0.323)
Number of Connections^2	0.777 (0.22) ***	-0.236 (0.274)
Total Circuit Length^2	0.303 (0.062) ***	-0.083 (0.146)
Volumes Carried x Ratcheted Max Demand	0.597 (0.611)	-0.009 (0.719)
Volumes Carried x Number of Connections	-0.067 (0.37)	0.559 (0.33)
Volumes Carried x Total Circuit Length	-0.719 (0.247) **	-1.441 (0.24) ***
Ratcheted Max Demand x Number of Connections	-1.206 (0.249) ***	-0.851 (0.387) *
Ratcheted Max Demand x Total Circuit Length	1.153 (0.253) ***	0.228 (0.353)
Number of Connections x Total Circuit Length	-0.932 (0.255) ***	1.274 (0.543) *
Year	0.02 (0.002) ***	0.027 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-35.67 (6.985) ***	-5.371 (19.129)
Ratcheted Max Demand	1.802 (0.659) **	2.861 (2.198)
Number of Connections	-1.994 (2.021)	-0.593 (2.67)
Total Circuit Length	3.988 (1.757) *	-4.126 (4.892)
Ratcheted Max Demand^2	0.514 (0.054) ***	0.027 (0.141)
Number of Connections^2	0.742 (0.266) **	-0.406 (0.644)
Total Circuit Length^2	0.136 (0.025) ***	0.088 (0.153)
Ratcheted Max Demand x Number of Connections	-1.202 (0.256) ***	0.577 (0.81)
Ratcheted Max Demand x Total Circuit Length	0.719 (0.292) *	-0.975 (0.95)
Number of Connections x Total Circuit Length	-0.881 (0.3) **	0.735 (1.047)
Year	0.019 (0.002) ***	0.016 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-25.641 (5.025) ***	-42.9 (10.851) ***
Total Circuit Length	1.133 (0.329) ***	-0.837 (1.854)
Number of Connections	-1.75 (0.306) ***	1.827 (1.267)
Reliability (Class B)	0.116 (0.109)	0.169 (0.073) *
Reliability (Class C)	-0.072 (0.186)	0.034 (0.137)
Total Circuit Length^2	-0.084 (0.059)	0.254 (0.15)
Number of Connections^2	0.05 (0.025) *	0.128 (0.15)
Reliability (Class B)^2	-0.006 (0.003)	-0.006 (0.002) **
Reliability (Class C)^2	0.023 (0.01) *	-0.005 (0.006)
Number of Connections x Reliability (Class B)	-0.013 (0.029)	-0.025 (0.021)
Number of Connections x Reliability (Class C)	0.044 (0.023)	0.019 (0.013)
Reliability (Class B) x Reliability (Class C)	-0.028 (0.028)	-0.033 (0.025)
Total Circuit Length x Number of Connections	0.084 (0.076)	-0.513 (0.368)
Total Circuit Length x Reliability (Class B)	0.074 (0.042)	0.096 (0.034) **
Total Circuit Length x Reliability (Class C)	-0.087 (0.041) *	0.048 (0.032)
Year	0.021 (0.003) ***	0.025 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	-17.539 (5.054) ***	-18.743 (6.15) **
Ratcheted Max Demand	4.393 (0.588) ***	7.644 (1.891) ***
Total Circuit Length	-0.241 (0.259)	0.772 (0.794)
Total Capacity	-3.617 (0.675) ***	-7.657 (1.867) ***
Ratcheted Max Demand^2	1.225 (0.317) ***	1.263 (0.248) ***
Total Circuit Length^2	0.089 (0.046)	-0.178 (0.084) *
Total Capacity^2	1.162 (0.477) *	0.655 (0.33) *
Ratcheted Max Demand x Total Circuit Length	-0.301 (0.175)	-0.861 (0.475)
Ratcheted Max Demand x Total Capacity	-2.264 (0.772) **	-1.997 (0.446) ***
Total Circuit Length x Total Capacity	0.117 (0.217)	1.146 (0.424) **
Year	0.016 (0.002) ***	0.016 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-25.141 (4.595) ***	-20.013 (5.044) ***
Ratcheted Max Demand	1.088 (0.334) **	2.025 (0.889) *
Total Circuit Length	-0.46 (0.241)	-1.159 (0.671)
Ratcheted Max Demand^2	0.126 (0.023) ***	0.161 (0.196)
Total Circuit Length^2	0.127 (0.034) ***	0.187 (0.105)
Ratcheted Max Demand x Total Circuit Length	-0.225 (0.064) ***	-0.323 (0.262)
Year	0.019 (0.002) ***	0.016 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	-3.87 (4.948)	-26.55 (21.781)
Number of Connections	-2.325 (0.559) ***	-1.127 (3.948)
Overhead Line Capacity	0.446 (0.122) ***	1.179 (1.43)
Underground Cable Capacity	1.532 (0.378) ***	0.255 (1.05)
Number of Connections^2	0.205 (0.044) ***	0.094 (0.203)
Overhead Line Capacity^2	0.021 (0.01) *	-0.014 (0.016)
Underground Cable Capacity^2	0.098 (0.022) ***	0.039 (0.025)
Number of Connections x Overhead Line Capacity	-0.019 (0.046)	-0.078 (0.173)
Number of Connections x Underground Cable Capacity	-0.202 (0.064) **	-0.052 (0.163)
Overhead Line Capacity x Underground Cable Capacity	-0.057 (0.032)	-0.009 (0.048)
Year	0.011 (0.003) ***	0.022 (0.005) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	-0.053 (5.243)	-26.616 (7.097) ***
Ratcheted Max Demand	1.234 (0.438) **	1.466 (1.103)
Overhead Line Capacity	-0.151 (0.132)	1.105 (0.438) *
Underground Cable Capacity	-0.451 (0.331)	0.21 (0.375)
Ratcheted Max Demand^2	0.289 (0.077) ***	0.207 (0.32)
Overhead Line Capacity^2	0.05 (0.008) ***	-0.002 (0.011)
Underground Cable Capacity^2	0.165 (0.036) ***	0.036 (0.042)
Ratcheted Max Demand x Overhead Line Capacity	-0.128 (0.043) **	-0.208 (0.157)
Ratcheted Max Demand x Underground Cable Capacity	-0.358 (0.112) **	-0.097 (0.207)
Overhead Line Capacity x Underground Cable Capacity	0.021 (0.033)	-0.016 (0.045)
Year	0.006 (0.003) *	0.016 (0.003) ***
EDB Fixed Effects	No	Yes

Exempt EDBs

	Model 1	Model 1 (FE)
Intercept	-20.219 (5.701) ***	5.874 (10.529)
Number of Connections	0.308 (0.606)	-6.635 (2.171) **
Total Circuit Length	-0.099 (0.628)	1.646 (2.216)
Number of Connections^2	-0.096 (0.061)	0.706 (0.132) ***
Total Circuit Length^2	-0.128 (0.051) *	0.545 (0.3)
Number of Connections x Total Circuit Length	0.265 (0.103) *	-0.95 (0.32) **
Year	0.015 (0.003) ***	0.017 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 2	Model 2 (FE)
Intercept	-8.633 (10.407)	25.662 (14.533)
Volumes Carried	8.114 (2.252) ***	3.569 (1.419) *
Number of Connections	1.5 (2.623)	-12.01 (3.282) ***
Total Capacity	-7.91 (2.353) ***	1.721 (1.604)
Volumes Carried^2	1.007 (0.594)	-0.205 (0.246)
Number of Connections^2	0.084 (0.261)	0.791 (0.234) ***
Total Capacity^2	-0.253 (0.672)	-0.266 (0.267)
Volumes Carried x Number of Connections	-1.789 (0.504) ***	-0.493 (0.358)
Volumes Carried x Total Capacity	-0.289 (1.097)	0.717 (0.472)
Total Capacity x Number of Connections	1.301 (0.504) *	-0.257 (0.312)
Year	0.007 (0.004)	0.017 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 3	Model 3 (FE)
Intercept	-83.7 (16.121) ***	46.014 (16.487) **
Volumes Carried	-4.088 (7.996)	7.568 (2.391) **
Ratcheted Max Demand	-14.304 (4.7) **	4.706 (2.489)
Number of Connections	11.989 (4.122) **	-12.528 (3.438) ***
Total Circuit Length	11.285 (4.337) **	-8.628 (3.39) *
Volumes Carried^2	-3.28 (1.803)	1.712 (0.68) *
Ratcheted Max Demand^2	-1.203 (0.764)	1.208 (0.339) ***
Number of Connections^2	-0.746 (0.314) *	0.547 (0.255) *
Total Circuit Length^2	-1.651 (0.264) ***	0.815 (0.327) *
Volumes Carried x Ratcheted Max Demand	2.477 (2.057)	-1.88 (0.922) *
Volumes Carried x Number of Connections	-0.52 (1.035)	-0.777 (0.372) *
Volumes Carried x Total Circuit Length	4.656 (1.536) **	-1.462 (0.707) *
Ratcheted Max Demand x Number of Connections	2.298 (0.703) **	0.008 (0.378)
Ratcheted Max Demand x Total Circuit Length	-1.585 (0.862)	-0.461 (0.528)
Number of Connections x Total Circuit Length	-0.474 (0.677)	0.678 (0.369)
Year	0.017 (0.003) ***	0.017 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 4	Model 4 (FE)
Intercept	-57.557 (15.524) ***	58.672 (15.767) ***
Ratcheted Max Demand	-10.891 (3.499) **	9.542 (2.078) ***
Number of Connections	2.575 (3.945)	-12.772 (3.564) ***
Total Circuit Length	13.219 (3.308) ***	-7.091 (3.103) *
Ratcheted Max Demand^2	-0.704 (0.303) *	0.688 (0.179) ***
Number of Connections^2	0.173 (0.346)	0.548 (0.269) *
Total Circuit Length^2	-0.712 (0.171) ***	0.6 (0.293) *
Ratcheted Max Demand x Number of Connections	0.289 (0.593)	-0.425 (0.3)
Ratcheted Max Demand x Total Circuit Length	1.806 (0.433) ***	-1.335 (0.269) ***
Number of Connections x Total Circuit Length	-0.903 (0.274) **	0.385 (0.362)
Year	0.014 (0.003) ***	0.014 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 5	Model 5 (FE)
Intercept	-21.472 (7.74) **	3.641 (12.933)
Total Circuit Length	0.438 (0.725)	1.651 (2.802)
Number of Connections	-0.003 (0.672)	-5.176 (2.449) *
Reliability (Class B)	0.443 (0.208) *	0.129 (0.183)
Reliability (Class C)	0.746 (0.176) ***	-0.107 (0.129)
Total Circuit Length^2	-0.135 (0.068) *	0.491 (0.325)
Number of Connections^2	0.054 (0.094)	0.641 (0.163) ***
Reliability (Class B)^2	0.003 (0.012)	-0.007 (0.008)
Reliability (Class C)^2	-0.002 (0.012)	0.016 (0.007) *
Number of Connections x Reliability (Class B)	0.056 (0.04)	0.028 (0.026)
Number of Connections x Reliability (Class C)	-0.179 (0.065) **	-0.044 (0.028)
Reliability (Class B) x Reliability (Class C)	-0.008 (0.023)	-0.016 (0.011)
Total Circuit Length x Number of Connections	0.154 (0.129)	-0.93 (0.372) *
Total Circuit Length x Reliability (Class B)	-0.116 (0.05) *	0.007 (0.041)
Total Circuit Length x Reliability (Class C)	0.155 (0.069) *	0.036 (0.031)
Year	0.012 (0.003) ***	0.014 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 6	Model 6 (FE)
Intercept	4.11 (5.875)	-1.219 (10.622)
Ratcheted Max Demand	10.516 (2.479) ***	3.325 (2.559)
Total Circuit Length	-0.293 (1.066)	-2.819 (3.392)
Total Capacity	-12.103 (2.467) ***	0.732 (2.464)
Ratcheted Max Demand^2	0.869 (0.45)	-0.154 (0.387)
Total Circuit Length^2	-0.2 (0.091) *	0.408 (0.286)
Total Capacity^2	0.463 (0.474)	-0.857 (0.293) **
Ratcheted Max Demand x Total Circuit Length	-1.216 (0.284) ***	-1.222 (0.377) **
Ratcheted Max Demand x Total Capacity	-1.402 (0.89)	1.441 (0.606) *
Total Circuit Length x Total Capacity	1.638 (0.282) ***	0.373 (0.384)
Year	0.011 (0.003) ***	0.008 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 7	Model 7 (FE)
Intercept	-23.465 (5.85) ***	7.799 (9.511)
Ratcheted Max Demand	-2.762 (0.837) **	5.216 (1.073) ***
Total Circuit Length	4.355 (1.17) ***	-6.589 (2.834) *
Ratcheted Max Demand^2	-0.142 (0.066) *	0.565 (0.087) ***
Total Circuit Length^2	-0.395 (0.115) ***	0.783 (0.226) ***
Ratcheted Max Demand x Total Circuit Length	0.565 (0.171) **	-1.198 (0.205) ***
Year	0.013 (0.003) ***	0.01 (0.002) ***
EDB Fixed Effects	No	Yes

	Model 8	Model 8 (FE)
Intercept	9.876 (6.265)	-27.436 (22.169)
Number of Connections	-3.42 (1.724) *	4.025 (5.529)
Overhead Line Capacity	0.303 (0.626)	0.752 (1.427)
Underground Cable Capacity	2.626 (1.149) *	-1.534 (1.724)
Number of Connections^2	0.341 (0.175)	-0.209 (0.361)
Overhead Line Capacity^2	0.062 (0.023) **	0.204 (0.075) **
Underground Cable Capacity^2	0.166 (0.064) **	-0.066 (0.078)
Number of Connections x Overhead Line Capacity	-0.076 (0.127)	-0.292 (0.213)
Number of Connections x Underground Cable Capacity	-0.403 (0.201) *	0.443 (0.291)
Overhead Line Capacity x Underground Cable Capacity	-0.043 (0.067)	-0.197 (0.075) **
Year	0.005 (0.002) *	0.011 (0.003) ***
EDB Fixed Effects	No	Yes

	Model 9	Model 9 (FE)
Intercept	3.244 (3.537)	-5.088 (5.28)
Ratcheted Max Demand	-3.302 (0.699) ***	1.188 (1.417)
Overhead Line Capacity	1.474 (0.483) **	-0.977 (0.712)
Underground Cable Capacity	1.813 (0.329) ***	1.594 (0.705) *
Ratcheted Max Demand^2	-0.357 (0.134) **	-0.394 (0.225)
Overhead Line Capacity^2	-0.085 (0.035) *	0.193 (0.048) ***
Underground Cable Capacity^2	0.03 (0.057)	-0.173 (0.058) **
Ratcheted Max Demand x Overhead Line Capacity	0.544 (0.113) ***	-0.198 (0.212)
Ratcheted Max Demand x Underground Cable Capacity	0.203 (0.169)	0.693 (0.216) **
Overhead Line Capacity x Underground Cable Capacity	-0.284 (0.05) ***	-0.231 (0.113) *
Year	0.002 (0.002)	0.008 (0.002) ***
EDB Fixed Effects	No	Yes

Appendix D FIGURES

D.1. Output indices

Figure 18: Model 1 (Circuit length, ICPs)

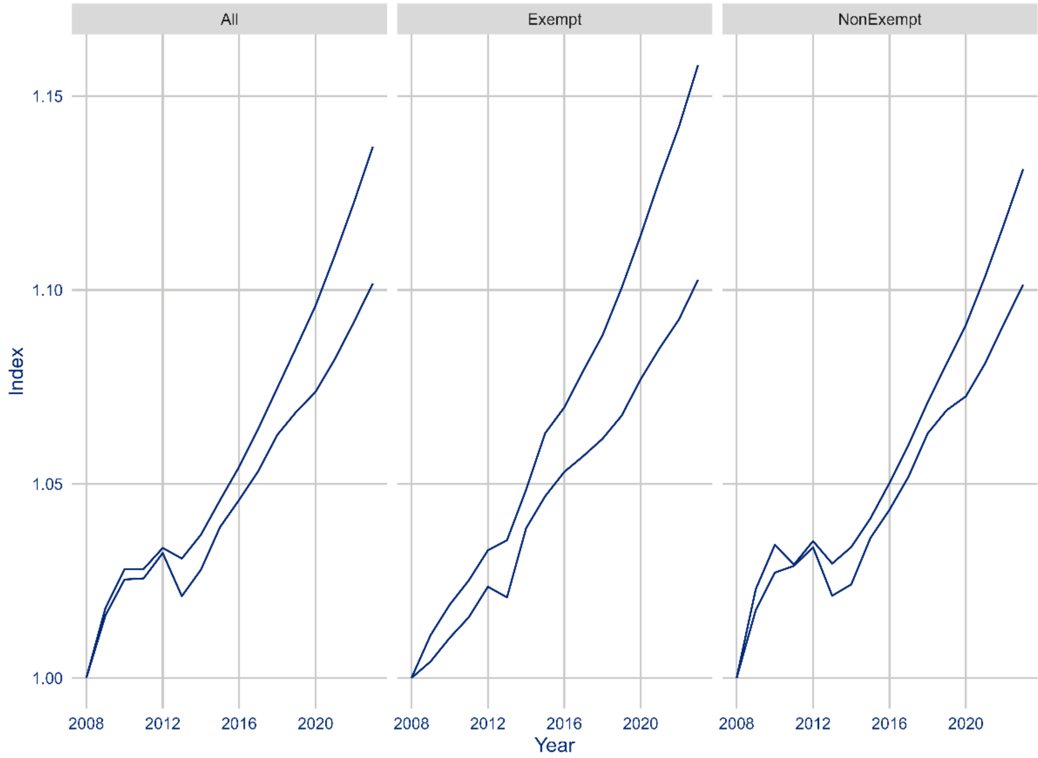


Figure 19: Model 2 (Energy delivered, customer numbers, transformer capacity)

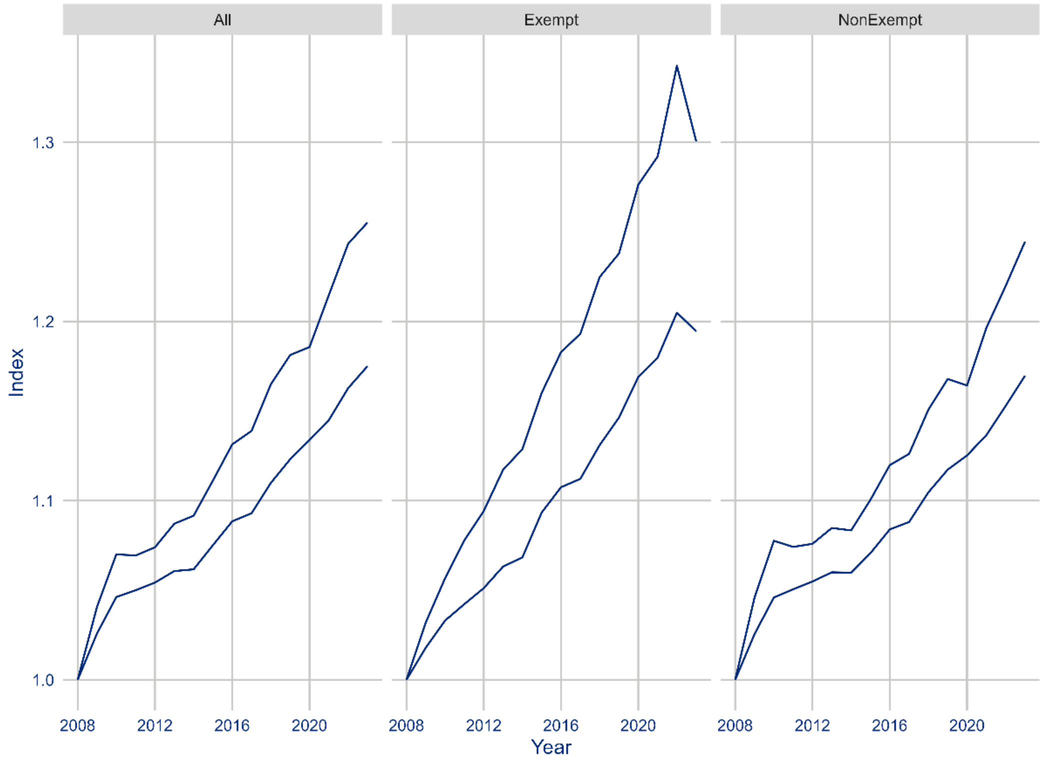


Figure 20: Model 3 (Energy delivered, ratcheted maximum demand, customer numbers, circuit length)

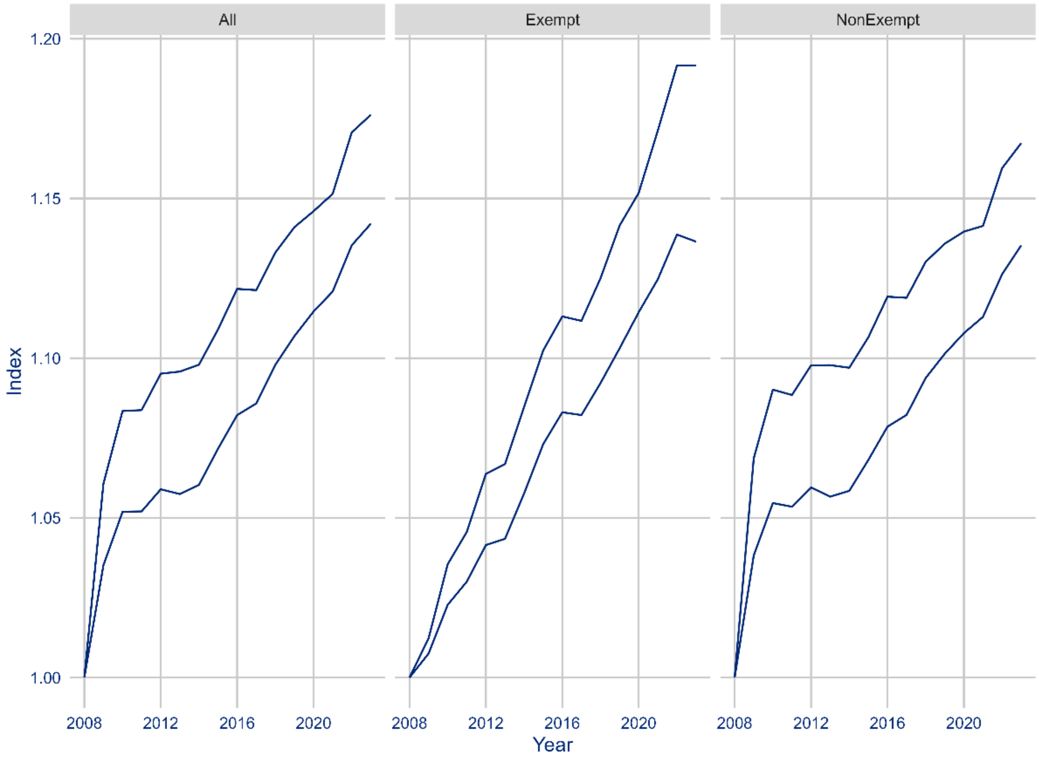


Figure 21: Model 4 (Ratcheted maximum demand, customer numbers, circuit length)

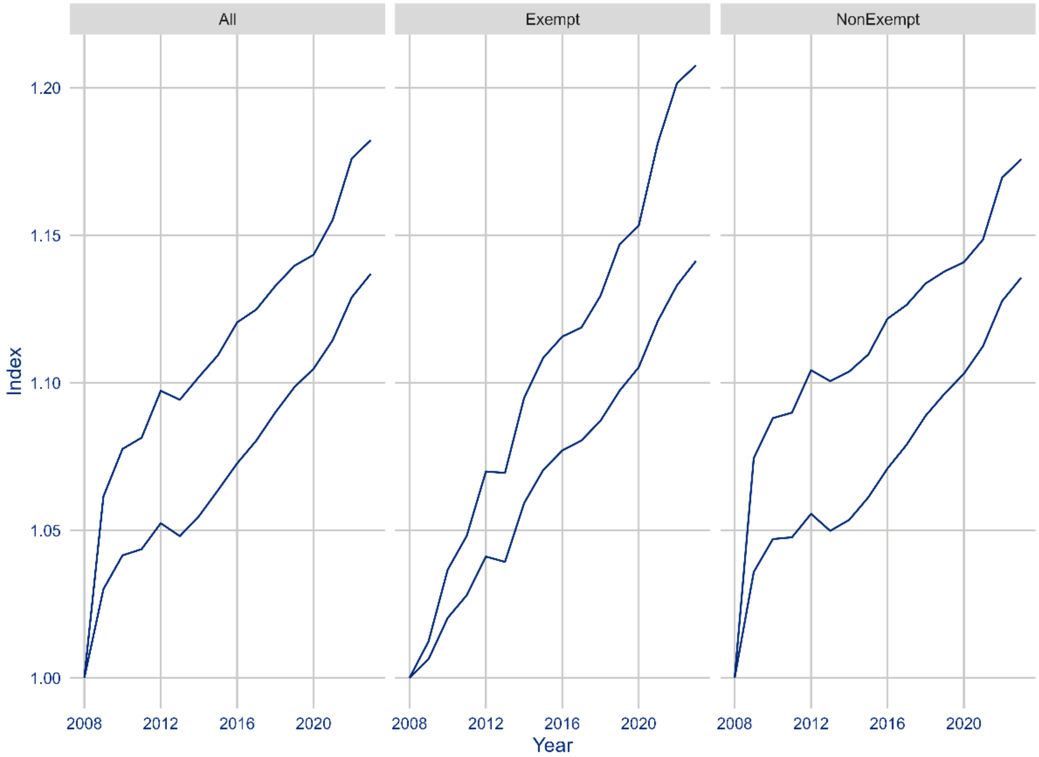


Figure 22: Model 5 (Circuit length, customer numbers, reliability)

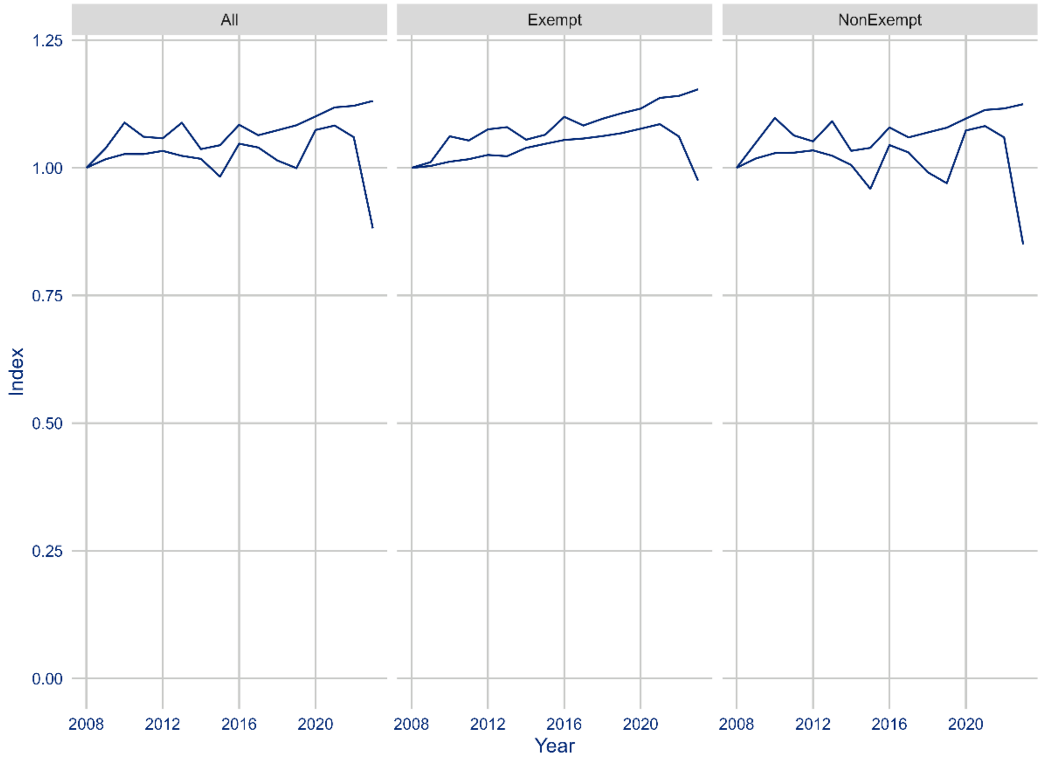


Figure 23: Model 6 (Ratcheted maximum demand, circuit length, transformer capacity)

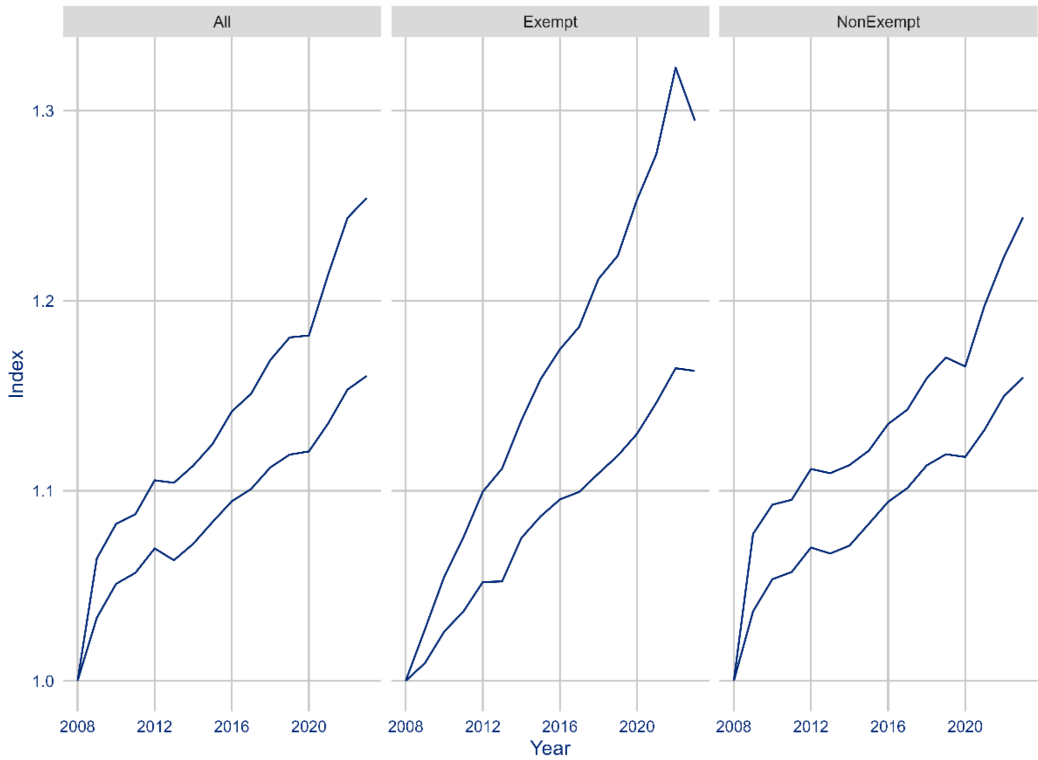


Figure 24: Model 7 (Ratcheted maximum demand, circuit length)

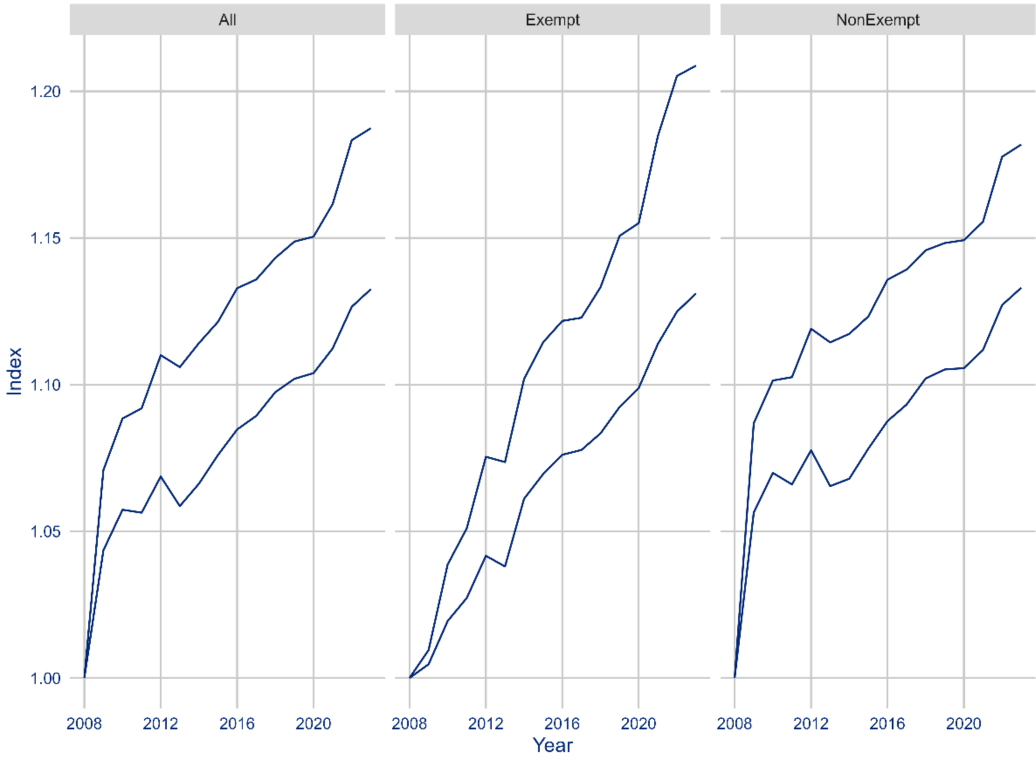


Figure 25: Model 8 (Customer numbers, overhead line capacity, underground cable capacity)

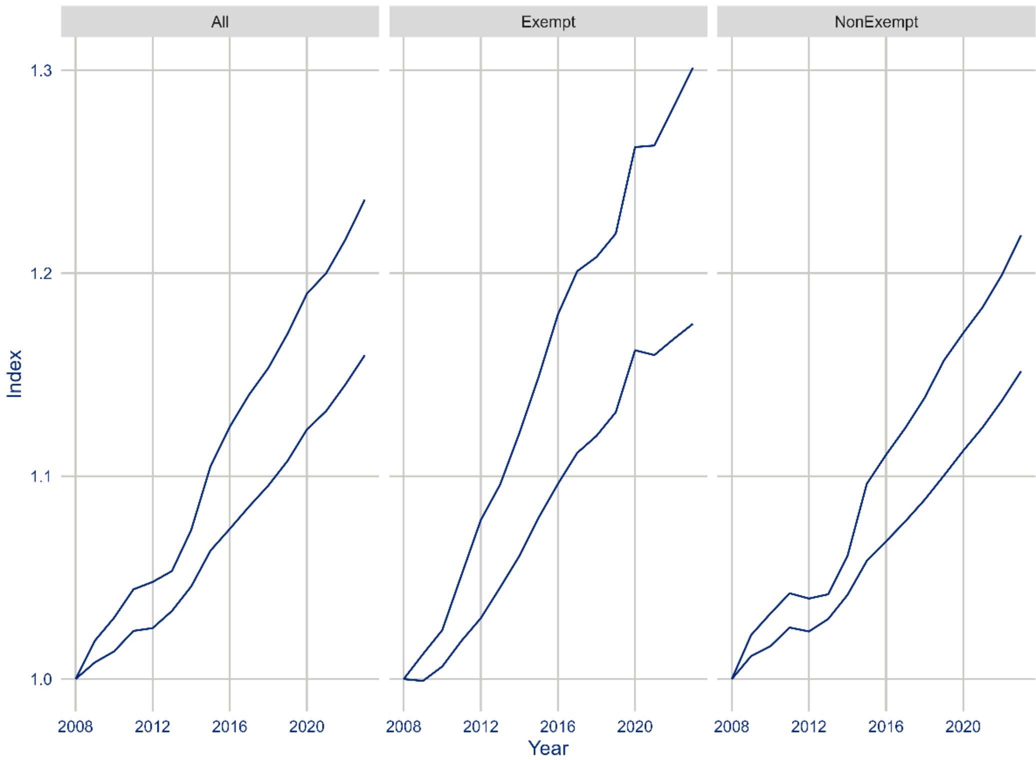
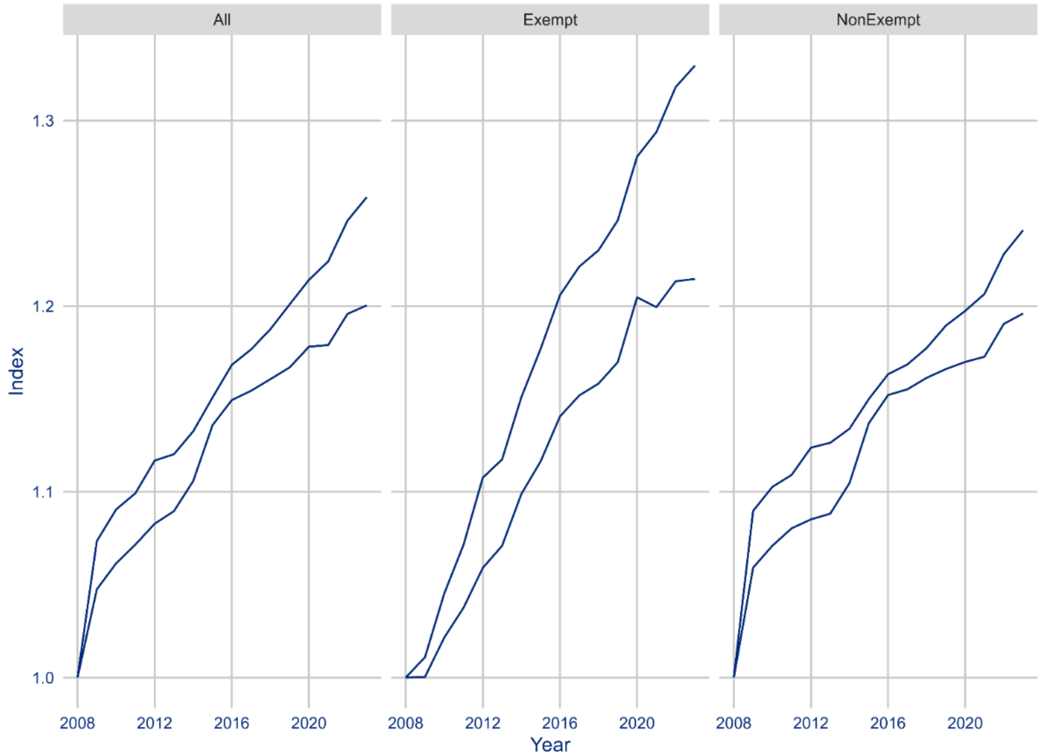


Figure 26: Model 9 (Ratcheted maximum demand, overhead line capacity, underground cable capacity)



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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McLellan (2004), Measuring Productivity using the Index Number Approach: An Introduction, New Zealand Treasury Working Paper, No. 04/05, New Zealand Government, The Treasury, Wellington.

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