



# **Application of a loss function simulation model to New Zealand**

**A REPORT PREPARED FOR TRANSPower**

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## Executive summary

Frontier Economics has been asked by Transpower to investigate the optimal WACC percentile that would be appropriate within a New Zealand context, for regulated electricity networks, by using the welfare loss function approach developed by Professor Ian Dobbs (Dobbs, 2011).<sup>1</sup>

We found that after making appropriate parameter adjustments to Dobbs' model to reflect the role of networks in the New Zealand electricity sector, and adopting reasonable input assumptions that reflect the characteristics of the electricity industry in New Zealand, the optimal WACC is likely to be considerably higher than the 75<sup>th</sup> percentile of the estimated WACC range. This is true under plausible input parameter values, even if a consumer welfare standard (as opposed to a total welfare standard) is adopted when assessing the optimal WACC percentile. This is because the welfare costs of under-investment accrue substantially more quickly than the welfare costs of over-investment. Importantly, these results were obtained while only considering the effect of the WACC on network investments that avoid unserved energy (i.e. reliability investments). They do not reflect the impact of the WACC on the likelihood of investment in, and the benefits of, 'economic' investments, which reduce the resource costs of dispatch (e.g. fuel savings).

Our first step involved building a simulation model, as set out in Dobbs (2011) and replicating the original results in that study. In order to apply this model to a New Zealand context, we calibrated it using inputs better reflecting features of the New Zealand electricity industry. This allowed us to obtain a base case result. Our application of the model assumed that the resulting WACC percentile would apply to both transmission and distribution networks, which leads to a larger impact on consumption from a higher allowed rate of return and produces a lower optimal WACC percentile than had we considered the transmission sector alone. We then conducted sensitivity analyses on the base case by varying the input assumptions.

While Dobbs found optimal WACCs generally fell within a range between the 70<sup>th</sup> and 90<sup>th</sup> percentile, the results in our base case scenario (embodying realistic, if conservative, input values for the New Zealand context) show that the optimal WACC is at the 99<sup>th</sup> percentile. This is principally due to the fact that (1) electricity demand tends to be highly inelastic – unlike Dobbs' assumption of relatively elastic demand; and (2) network costs only make up roughly one third of the average final electricity bill. Therefore, a small increase in network prices has relatively little impact on retail tariffs and hence, the quantity of final

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<sup>1</sup> Dobbs, I.M., "Modeling welfare loss asymmetries arising from uncertainty in the regulatory cost of finance", *Journal of Regulatory Economics* (2011) Volume 39, pp.1-28.

consumption. This means that the impact of adopting a higher WACC percentile on economic welfare is very small compared to the loss in welfare that arises when underinvestment occurs.

The sensitivity analyses we conducted suggests that our base case result is robust to using plausible alternative inputs for the New Zealand electricity network industry. Quite extreme (and unrealistic) parameter assumptions were required to generate results at the 50<sup>th</sup> and 70<sup>th</sup> percentiles. Even focussing solely on a consumer surplus measure of welfare produced an optimal WACC at the 87<sup>th</sup> percentile (leaving other inputs as before).

We recognise that this report reflects the first iteration of an application of the Dobbs model to the New Zealand electricity sector. We note that the modelling utilises key parameters that could potentially be tested (some empirically), but this would require consultation, which has not been practicable within the available timeframes. Nevertheless, we believe that our analysis is far more robust and offers much more useful insights than the intuitive and well-presented, but ultimately simplistic modelling produced by Oxera. Rather than estimating the extent of under-investment from an inadequate allowed rate of return based on an arbitrary ‘rule of thumb’, as Oxera did, our application of the Dobbs model estimates under-investment endogenously within the model.

Our overall conclusion, based on our modelling results, is that the Commission’s current approach of adopting the 75<sup>th</sup> WACC percentile, when setting allowed rates of return for regulated electricity networks in New Zealand, is likely to be conservatively low.

# 1 Introduction

## 1.1 Background

Frontier Economics (Frontier) has prepared this report for Transpower New Zealand (Transpower) to inform Transpower's response to the Commerce Commission's Draft Decision on proposed changes to the WACC percentile for electricity lines services and gas pipeline services.<sup>2</sup>

This report discusses our approach to and our results from attempting to replicate and extend the loss modelling analysis originally undertaken by Professor Ian Dobbs (Dobbs, 2011).

In summary, our modelling:

- Replicates Dobbs' results.<sup>3</sup>
- Re-calibrates Dobbs' model inputs to reflect better the relevant characteristics of the demand for electricity network services, the impact of network prices on end-use electricity tariffs, the nature of the underlying WACC distribution and the key regulatory parameters applicable to Transpower and distribution lines businesses in New Zealand.
- Produces results for the optimal WACC percentiles arising under various combinations of more input assumptions that are more realistic for New Zealand than those used in Dobbs (2011).

This report also addresses the main reservations about the Dobbs model expressed by various experts, submitters and the Commission, through the Commission's consultation process.

## 1.2 Structure

This report is structured as follows:

- Section 2 provides an overview of the Dobbs model, its key results and how it compares to Oxera's modelling approach and results.<sup>4</sup>

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<sup>2</sup> Commerce Commission, *Proposed changes to the WACC percentile for electricity lines services and gas pipeline services, Public version*, 22 July 2014 (Commission's Draft Decision).

<sup>3</sup> In the process of replicating Dobbs' results, we uncovered a minor error in Dobbs' calculations, which arose from limitations in computing power available to Dobbs. We were able to confirm this through correspondence with the author. Our modelling therefore represents a slight improvement on the accuracy of the results in Dobbs (2011). More on this in the Appendix to this report.

<sup>4</sup> Oxera, *Input methodologies, Review of the '75<sup>th</sup> percentile' approach, Prepared for the New Zealand Commerce Commission*, 23 June 2014.

- Section 3 discusses and provides the rationale for our base case input assumptions for electricity demand, network price pass-through to end customer tariffs, the WACC distribution and other regulatory parameters.
- Section 4 first describes our modelling results under the base case assumptions. It then investigates how robust the base case results are to alternative, but reasonably plausible input assumptions, including the use of a consumer surplus-only welfare criterion. Finally, it investigates how extreme the input values to the model would need to be in order to give optimal WACC percentiles significantly lower than the 75<sup>th</sup> percentile presently employed by the Commission.



## 2 Overview of Dobbs' model

Dobbs (2011) studied the overall welfare implications of setting the allowed rate of return at different levels within an estimated WACC range, i.e. given uncertainty about the regulated supplier's 'true' WACC. He found that the optimal allowed rate of return for a regulated supplier was generally well above the 50<sup>th</sup> percentile of the WACC distribution. The driver for the upward skew in the distribution of optimal allowed rates of return was the asymmetric effects of:

- An allowed rate of return *in excess of* the true WACC: The negative effects of a 'too high' return were limited to a small reduction in demand and hence a small reduction in economic welfare.
- An allowed rate of return *below* the true WACC: The negative effects of a 'too low' return were derived from (i) the supplier choosing not to proceed with welfare-enhancing new investments; and (ii) consumers demanding more of the service than is efficient.

The sum of the negative effects of the latter outweighed greatly the negative effects of the former.

### 2.1 Dobbs' framework and methodology

The basic framework in Dobbs (2011) involved the regulator setting an allowed rate of return applicable to a regulated supplier and then determining a price control applicable throughout a regulatory control period. The regulator must set the allowed rate of return in an environment of uncertainty, that is, without knowing the supplier's true WACC.

The paper derived an optimal allowed rate of return for the supplier by maximising a total welfare (i.e. consumer surplus plus producer surplus) function for the regulated service. This function took account of the rate of return allowed by the regulator and the investment decision faced by the supplier once it has observed the regulator's determination. In particular, after learning its true cost of finance and the allowed WACC set by the regulator, the supplier can choose to not invest in the current regulatory period. Given the allowed WACC, the supplier will undertake the investment if and only if the allowed rate of return exceeds a certain hurdle rate, where this hurdle rate needs to be determined endogenously within the model.

Under these conditions, the more the regulator raises the allowed WACC above the median of the distribution:

- The higher the likelihood of investment will be, and the more likely that the welfare loss from underinvestment will be avoided.
- *Conditional on investment occurring*, the allowed WACC is more likely to be above the true cost of finance. Consequently the price is higher than the efficient level, resulting in welfare loss due to marginal reduction in demand compared to the optimal level.

Taking account of the trade-off above, the regulator is able to maximise total welfare (i.e. minimise the losses to total welfare) by choosing an appropriate allowed rate of return.

Given the complexity of the welfare function, a ‘closed form’ (i.e. analytical) solution to this optimisation problem is not available, even if a very simple WACC distribution is assumed. Therefore, Dobbs (2011) solved the optimisation problem numerically using Monte Carlo simulation analysis.

Dobbs separately considered and evaluated the solution for the three types of investment that a regulated supplier may own:

- ***Sunk investments*** (i.e. assets already in the RAB) – **Category 1.**
- ***Prospective non-deferrable investments*** (i.e. future investments that the supplier has no timing flexibility over, so the choice the supplier faces is to invest now or never) – **Category 2.**
- ***Prospective deferrable investments*** (i.e. future investments that may be delayed to later regulatory periods) – **Category 3.**

In addition, Dobbs investigated cases in which the supplier owns a mix of sunk and prospective investments. In almost all of the cases examined, Dobbs found the optimal WACC to be well above the 50<sup>th</sup> percentile (see below).<sup>5</sup>

## 2.2 Summary of Dobbs’ key assumptions and results

Throughout his analysis, Dobbs applied a normal WACC distribution with a mean of 10% and standard deviation of 1.5%.<sup>6</sup> Dobbs provided optimal WACC percentiles for each category of investment and for a mix of investment categories given a wide range of input parameters.

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<sup>5</sup> The only exceptions are cases where the own-price elasticity of demand is -6. This reflects scenarios where the percentage reduction in consumption is 6 times larger than the percentage increase in price. This assumption implies that the welfare loss due to reduced consumption is extremely high. However, it is clear that such an elastic demand function is not applicable to consumption of “necessities” such as electricity.

<sup>6</sup> Dobbs (2011), p.15.

## 2.2.1 Key parameter assumptions

The relevant input variables adopted by Dobbs were as follows:<sup>7</sup>

- **Marginal cost of investment:** benchmark value of 1; sensitivity of 0.
- **Capital cost of investment:** benchmark value of 10; sensitivities of 20 and 100.<sup>8</sup>
- **Depreciation rate:** benchmark value of 0.1 (i.e. 10% per annum); sensitivity of 0.
- **Demand growth rate:** benchmark value of 0; sensitivity of 0.05 (i.e. 5% per annum).
- **Demand elasticity:** benchmark value of -3; sensitivities of -6 and -1.5.
- **Regulatory review period:** benchmark value of 5 years; sensitivities of 3 and 7 years.

## 2.2.2 Investment category results

The optimal WACCs for each category of investment in Dobbs (2011) can be summarised as follows:<sup>9</sup>

- **Category 1** (Sunk investments): **45<sup>th</sup>** percentile in the benchmark case and results ranged from the **43<sup>rd</sup>** to the **45<sup>th</sup>** percentiles.
- **Category 2** (Prospective non-deferrable investments): **86<sup>th</sup>** percentile in the benchmark case and results ranged from the **68<sup>th</sup>** to the **91<sup>st</sup>** percentiles. Lower percentile results were obtained with positive demand growth (i.e. 5%), a higher elasticity (i.e. -6) and a shorter regulatory period (i.e. 3 years). Higher percentile results were obtained with a lower elasticity (i.e. -1.5) and a longer regulatory period (i.e. 7 years).
- **Category 3** (Prospective deferrable investments): **97<sup>th</sup>** percentile in the benchmark case and results ranged from the **79<sup>th</sup>** to the **98<sup>th</sup>** percentiles. As with category 2, lower percentile results were obtained with positive demand growth, a higher elasticity and a shorter regulatory period. Higher percentile results were obtained with a lower elasticity and a longer regulatory period.

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<sup>7</sup> Dobbs (2011), Table 2, p.18.

<sup>8</sup> Table 2 of Dobbs (2011) also has capital cost = 0 in case 6. However, this is likely to be a typographical error as  $K = 0$  would imply the regulated price would not change with the regulated WACC as per equation 7 in the paper. The correct number should be  $K = 10$  and the intention of this case is to investigate the effect of less elastic demand. We have confirmed this by replicating Dobbs' original number in case 6 with  $K = 10$ .

<sup>9</sup> Dobbs (2011), Table 2, p.18.

### 2.2.3 Mixed investment results

As noted above, Dobbs also calculated optimal WACC percentiles for businesses with a mix of sunk and prospective investments. He assumed zero non-deferrable investments (category 2) and derived optimal WACCs where businesses had varying proportions of sunk (category 1) and deferrable new investment (category 3). Most commonly, Dobbs assumed that category 3 investment made up 10% of total investment. However, Dobbs also considered sensitivities of 5%, 20% and 30%.

Under the benchmark assumptions, Dobbs found the optimal WACC lay at the **82<sup>nd</sup>** percentile.<sup>10</sup> Results ranged from the **48<sup>th</sup>** percentile to the **90<sup>th</sup>** percentile.<sup>11</sup>

- Lower results were obtained particularly when a higher elasticity was applied to the demand for services provided by deferrable (category 3) investment than for services provided by sunk (category 1) investment. More generally, lower results were obtained with a smaller proportion of category 3 investment, a lower marginal cost, a higher capital cost, a higher demand elasticity, and a positive demand growth rate.
- Higher results were obtained with a higher proportion of deferrable investment and a smaller demand elasticity.

## 2.3 Response to claims of potential limitations of the Dobbs model

The Commission's Draft Decision noted a number of potential limitations of the analysis in Dobbs (2011) raised by Dr Martin Lally and Professor Ingo Vogelsang (two of the Commission's experts) and in stakeholder submissions. While we agree these matters should be addressed, which we do below, we do not consider that they undermine the relevance of Dobbs' analysis for the Commission's present considerations. Table 1 summarises the key claimed limitations of the Dobbs model, and our responses to those contended limitations

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<sup>10</sup> Note that Dobbs described 10% of category 3 investment as his benchmark in Table 4, p.22; this contradicts the Commission's Draft Decision statement that Dobbs' base case estimate is the 74<sup>th</sup> percentile. That result reflects only 5% of category 3 investment, which was only applied once (in row 1 of Table 3, p.21).

<sup>11</sup> Dobbs (2011), Table 3, p.21.

Table 1: Claimed limitations of the Dobbs model and Frontier responses

Contended limitation		Summary response
1	Inappropriate demand elasticities used	Addressed through use of more plausible elasticity values
2	Equal weight inappropriately placed on consumer and producer surplus	Disagree with the basis for this claim – but addressed through a consumer surplus-only sensitivity
3	Allowed rate of return below required level may not necessarily cause investment to cease	There is a range of potential harmful responses to an allowed rate of return set too low
4	Incentives for over-investment ignored	Transpower is already subject to the Investment Test and is likely to face more constraints on over-investment over time
5	Impacts on inter-sectoral welfare and user investments ignored	Taken account of through use of appropriate elasticity
6	'True' WACC unobservable	This actually suggests the results are conservatively low
7	Ignores scope for regulators to adjust allowed rate of return in light of experience	Ex post WACC adjustments cannot avoid permanent losses due to past sub-optimal decisions caused by an inappropriately low allowed rate of return

Source: Frontier Economics

In addition, we raise an additional limitation of the Dobbs model that indicates that a higher WACC percentile should be used – the fact that it takes no account of economic benefits from transmission investment outside avoided unserved energy.

We summarise the potential limitations below and respond, briefly, to each. In any case, the Commission noted that despite these limitations, Dr Lally concluded that the Dobbs model provided the best available analysis of the issues.<sup>12</sup> We agree with Dr Lally's assessment in this regard.

### **Demand elasticity range**

Dobbs applied a benchmark value of -3 for the own-price elasticity of demand, with sensitivities of -6 and -1.5. We agree that this range does not appropriately reflect the elasticity typically estimated for electricity consumption. Therefore, in adapting the Dobbs model to estimate the optimal WACC for electricity

<sup>12</sup> Commission's Draft Decision, paras 5.9 and 5.34.

networks, we applied a more appropriate range of elasticity parameters (see below).

### ***Equal weight placed on consumer and producer surplus***

The appropriate degree of weight to be placed on producer surplus has been a matter of some contention in New Zealand (not just in the context of this issue, but also in various regulatory and competition matters that Commission has adjudicated on).

Our view is that, from an economic perspective, it would not be sensible for a regulator to favour consumer welfare and ignore altogether producer welfare. Firstly, there is no sound economic reason to favour consumers over producers. Secondly, consumers benefit from investments made by producers, and producers are motivated by profits (i.e. surpluses) to invest. Regulatory policies that focus narrowly on the interests of consumers may give rise to incentives for producers to behave in such a way that harms consumers in the long-run (e.g. by curtailing welfare-enhancing investment).<sup>13</sup> Finally, the regulatory objective in section 52A of the *Commerce Act* 1986 refers to promoting the long-term interests of consumers “...by promoting outcomes that are consistent with outcomes produced in competitive markets...”. A competitive market can only operate at a stable equilibrium if producers are able to recover their efficient costs. If firms in a competitive market cannot recover their efficient costs, they will exit the market until prices rise sufficiently for an equilibrium to be restored in which efficient costs can be recovered. This suggests that ignoring the interests of producers altogether would not be consistent with the regulatory objective.

Notwithstanding our reservations over some submitters’ contention that the Commission should focus exclusively on consumer welfare, we note that it is possible to modify Dobbs’ model in such a way that optimal WACC percentile is chosen so as to maximise consumer (rather than total) surplus. We have undertaken this exercise and find that under reasonable input assumptions the optimal WACC percentile still exceeds the 75<sup>th</sup> percentile (see below).

### ***Likelihood of investment ceasing due to inadequate WACC***

Electricity networks in New Zealand like in many jurisdictions are subject to legislative and licence obligations to maintain stipulated reliability standards. However, if these obligations are the *only* driver to network investment, then an inadequate WACC is likely, in the long run, to result in:

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<sup>13</sup> To see the problem with focussing narrowly on static consumer welfare, note that consumer welfare could be maximised by setting all regulated prices to zero. This would result in a total transfer of welfare from producers to consumers. However, this would also undermine altogether producers’ incentives to continue offering the services that consumers value.

- a fall in the market value of network businesses (e.g. due to regulated suppliers effectively investing even when there is no business case to do so); and/or
- incentives that may not be compatible with the broader regulatory framework e.g. inefficient investment decisions, inefficient substitution of opex for capex.

The Electricity Authority has commented recently on the level of discretion available to Transpower with regards reliability investments. It considers that Transpower has “wide discretion available ... in determining how to meet the GRS”.<sup>14</sup> Consistent with the Electricity Authority’s view, Castalia have noted that “a low WACC would encourage a rational transmission company to take available opportunities to defer or avoid capital expenditure ... The impact on consumers could include ... A higher total cost of electricity supply due to a shift at the margin towards opex (and away from capex). This would raise the whole of life costs of providing transmission services, and could create the need for periods of “catch up” investment”.<sup>15</sup>

Moreover, these obligations do not affect the likelihood of, or incentives for, networks to invest in discretionary ‘market benefit’-type investments (e.g. augmentation of the network to serve new customers, as opposed to investing in the existing network to maintain service standards to existing customers).

### **Risk of over-investment**

As noted in our previous report, New Zealand has in place regulatory arrangements designed to prevent inefficient over-investment by Transpower. In particular, ‘major capex’ projects may only be approved by the Commission if they satisfy the Investment Test in Schedule D of the Transpower Capital Expenditure Input Methodology. Under these conditions, the likelihood and hence costs of over-investment are likely to be curtailed significantly, even if the allowed rate of return is set above Transpower’s true WACC. (The alternative assumption would be that the existing arrangements are ineffective in preventing major over-investment, which seems unlikely.)

Further, we understand that efficiency incentives are being introduced for the next control period that will mitigate the risk of over investment for electricity distribution businesses and further mitigate that risk for Transpower.<sup>16</sup>

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<sup>14</sup> Electricity Authority, Working Paper, Transmission Pricing Methodology: Connection charges, 13 May 2014, paragraph 7.26.

<sup>15</sup> Castalia, Report to Transpower, The Rational Response of a Regulated Transmission Company to a Low WACC, 1 May 2014, page iii.

<sup>16</sup> We refer to the Commission’s proposals to extend the ‘incremental rolling incentive schemes’ to include electricity distribution businesses (opex and capex) and to include capex for Transpower.



### **Wider sectoral and investment impacts**

Another objection to the Dobbs model is that it ignores the ‘flow-on’ effects of higher electricity prices on downstream businesses that use electricity as an input to their production processes. However, as noted by Dr Lally, as long as the own-price elasticity of demand for electricity is appropriately specified, the results of the Dobbs analysis should reflect the implications of different WACC percentiles on electricity users (and the economy) more broadly.

### **Unobservable true WACC**

Dr Lally notes that because businesses cannot know their true WACC, this means that an even higher WACC percentile should be used. In our view, this does not invalidate the Dobbs analysis; rather it suggests that the percentile results produced by the model should be seen as conservatively low.

### **Scope for regulators to adjust the allowed rate of return**

It is true that Dobbs’ model does not allow for regulators to react to low outturn investment, in an *ex post* fashion, by raising allowed returns in the future. However, a strategy of relying on the regulator to react to sub-optimal investment outcomes by raising the allowed rate of return going forward is problematic because many of the welfare losses could be permanent. For example, if the WACC is set too low:

- Efficient investment may be deferred;
- Operating expenditure may be inefficiently substituted for capital expenditure;
- Network assets may be sub-optimally-sized to delay expenditure; and
- Equipment procured may be of lower quality to save costs

If the regulated supplier engages in any of these behaviours, a subsequent reaction by the regulator to increase allowed returns in future will be too late to avoid permanently foregoing welfare from the inefficient decisions that have already occurred. Further, in principle, such an approach could lead to regulated suppliers seeking to game the regulator by holding off on investment unless and until they receive a higher allowed return.

### **Consideration for reduced generation cost**

Applied to electricity networks, the benefits from network investment considered in the Dobbs model arise exclusively from the avoided welfare loss associated with unserved demand.

Whilst not a point raised by submitters or the Commission, we note that the model does not take into consideration that network augmentation, by alleviating transmission constraints, also reduces the resource costs of generation by



facilitating export of energy from regions with cheaper generation resources and by reducing physical transmission losses. In this way, transmission investment can help avoid the need to expend society's resources on generation capital and operating (e.g. fuel) costs.

Although incorporating this benefit into Dobbs' modelling framework would be difficult, the benefit of reduced generation cost lends directional support to a higher allowed rate of return, all else being equal.

## 2.4 Comparison with Oxera's model

In its report to the Commission, Oxera recommended that:

"a point estimate around the 60<sup>th</sup> or 70<sup>th</sup> percentile appears to provide a suitable balance between the costs and benefits of the approach of setting a higher percentile in mitigating the risks associated with the underinvestment problem, and should therefore achieve the intended benefit of the WACC percentile approach."<sup>17</sup>

Oxera based its recommendation on the following trade-off from an increase in WACC: increase in charges to consumers and the avoided cost of network outage as underinvestment becomes less likely. We note that treating the entire increase in charges to consumer as a loss in welfare is to assume implicitly that producer profit/surplus is not included in the regulator's objective function.

The main difference between Dobbs'/Frontier's model and Oxera's analysis is that in the former, the (under)investment decisions as well as its welfare consequences are determined endogenously within the model, as opposed to be based on some rule of thumb assumptions. Oxera's analysis assumed that firms will withhold investment when the regulated WACC is less than the actual WACC by 0.5% to 1.0%. It is unclear why this assumption is made and whether this takes into account of the firms' expectation of the future movement in WACC. For example, when investment can be deferred, the firm should be able to withhold its investment if the actual cost of finance is higher than the allowed rate of return. Assuming that the firm will under invest *only if* the shortfall is at least 0.5% could potentially underestimate the cost of delayed investment.

## 2.5 Our conclusion on the usefulness of the Dobbs model

In summary, we agree with Dr Lally's assessment that the Dobbs model is the best framework available, at present, to analyse the question of the appropriate

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<sup>17</sup> Oxera, *Input methodologies, Review of the '75<sup>th</sup> percentile' approach, Prepared for the New Zealand Commerce Commission*, 23 June 2014, p73

WACC percentile. Although some submitters have proposed limitations to the Dobbs model, we consider that those claimed limitations are unfounded. Like all economic models the Dobbs model does have limitations, but we do not think that these undermine its usefulness in informing the Commission's decision-making.

In order to make the model as helpful as possible, it should be operationalised within a New Zealand context, and to reflect the realities of electricity supply networks. We have attempted to do just this.

The process we followed involved the following steps:

- First, we sought to replicate the results in Dobbs (2011). We succeeded in doing this but, in the process, we uncovered a relatively minor error in the original model, which we were able to correct (see the Appendix to this report for further details).
- Second, we extended and adapted the model where necessary in order to apply it to a real industry, and calibrated the model with values that we consider most reasonable to reflect the features of the electricity industry in New Zealand. This formed our 'base case' scenario (see section 3).
- Third, we ran the model under those assumptions and generated some base case results (see section 4).
- Finally, we conducted various sensitivity analyses by varying our base case assumptions (see section 4).

The source code of simulation was written in the statistical software "R", which is widely used by quantitative researchers in many disciplines. In order to help Transpower to better understand the working of the model, we will also integrate our source code with a user-friendly excel front-end, which we will provide to Transpower. The model may be audited fully. Transpower may share this model with the Commission if it wishes. A schematic of the model and its user interface can be found in Appendix B.

### 3 Base case input assumptions

This section discusses and provides the rationale for the key input assumptions adopted in our base case simulation. The scenario selected for the base case consists of inputs that are mostly likely to be representative of the New Zealand electricity industry. Our simulation model is based on Dobbs (2011). However, some elements of Dobbs' original model needed to be modified to reflect properly the characteristics of the electricity industry. These extensions and the reasons for them are explained in the relevant sections below.

A summary of the input assumptions for the base case is presented in Table 2.

Table 2: Scenario parameter inputs

Parameter	Base case scenario
Retail price (starting point on demand curve)	\$186.77/MWh
Demand served by existing investment (at starting point on demand curve)	38.85 TWh
Demand served by new investment (at starting point on demand curve)	1% of existing = 0.39 TWh
Elasticity of demand	-0.3
Maximum willingness to pay	\$20,000/MWh
Demand growth (existing)	0 %
Demand growth (new)	1%
Transmission price (at starting point)	\$21.96/MWh
Distribution Price (at starting point)	\$44.69/MWh
WACC distribution	Normal truncated at $\pm 4$ std dev
WACC mean	6.83%
WACC standard deviation	1.067%
Network fixed cost component	70%
Annual depreciation	2.5%
Regulatory length	5 years

Source: Frontier Economics

*Note: Most of the input values in this table cannot be compared directly with the inputs in Dobbs' model for two reasons. Firstly, the demand function in Dobbs' model is unitless, whereas in order to apply the model in a New Zealand context we have had to unitise the demand function. Secondly, the original Dobbs model does not offer a pass through treatment of network costs to retail prices, whereas our extended model does.*

## 3.1 Demand

### 3.1.1 Demand elasticity

Dobbs (2011) reported the optimal WACC results obtained with different values of the own-price elasticity of demand. In all cases in his original work, demand for the good or service in question was assumed to be relatively elastic; that is, a given percentage change in price would result in a larger percentage change in the quantity demanded. The primary demand elasticity value Dobbs chose was -3, with sensitivities of -1.5 and -6.

By contrast, the own-price elasticity of demand for electricity is generally regarded as being relatively inelastic due to the nature of electricity as a ‘necessity’. Further, while demand for electricity in the short run can be very inelastic, it is conceivable that users will find substitutes and alter their consumption behaviour over time. Hence, electricity demand can be more elastic (or, more accurately, less inelastic) in the long run than in the short run.

A more *inelastic* demand leads to a *higher* optimal WACC. This is because with an inelastic demand curve, there is less deadweight loss for a given price increase due to the smaller percentage reduction in consumption. On the other hand, an inelastic demand also implies a larger total surplus. Therefore, the loss of total surplus will also be larger when a reduction in price causes the firm to defer its investment.

We note that estimates of demand elasticities for electricity suggest that demand is relatively inelastic. For example, the Electricity Authority noted recently a short-term elasticity of -0.01 was “not unreasonable” given the penetration of advanced metering.<sup>18</sup> Such an elasticity would effectively imply next to no allocative inefficiency from setting the allowed rate of return for networks (and effectively, prices) higher than necessary to induce investment.

In a survey of demand elasticity estimates, Fan and Hyndman (2011) noted elasticities between -0.002 and -0.7, depending on the type of customer and the time frame involved.<sup>19</sup> Drawing on Fan and Hyndman’s work, the Australian Productivity Commission adopted an elasticity range of -0.2 to -0.4 in the short term and -0.5 to -0.7 in the long term.<sup>20</sup> Note that all of these estimates are much smaller (in absolute terms) than the -1.5 used by Dobbs in his sensitivity analyses.

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<sup>18</sup> Electricity Authority (2014), *Transmission pricing methodology review: Beneficiaries-pay options*, Working Paper, 21 January, para 7.62. p.42.

<sup>19</sup> Fan, S. and Hyndman, R. (2011), ‘The price elasticity of electricity demand in South Australia’, *Energy Policy*, Vol. 39, pp. 3709–19.

<sup>20</sup> Productivity Commission (2011), *Carbon Emission Policies in Key Economies*, Research Report, 9 June, Appendix L, *Demand-side analysis for electricity*, Box L.2., p.4.

Our base case scenario assumes that the elasticity is -0.3.

### 3.1.2 Maximum willingness to pay

Dobbs' original model was not designed to accommodate an inelastic demand for the relevant output. This is because Dobbs' model incorporated a constant elasticity of demand, implying a convex rather than linear demand function. With a constant elasticity of demand, consumer surplus becomes infinite when demand is inelastic.<sup>21</sup> To make the analysis meaningful, we altered Dobbs' model by assuming that consumers have a maximum willingness to pay for electricity.

A higher maximum willingness to pay implies a higher total surplus and thus a larger welfare loss when investment is deferred. For our base case scenario, we assumed the maximum willingness to pay (in NZ dollars) is \$20,000/MWh.

The basis for this central value lies in the current Electricity Industry Participation Code, which contains a default value of \$20,000/MWh.<sup>22</sup> This value was initially suggested to the Electricity Commission by Frontier Economics in 2004 based on research available at that time. More recent Australian estimates of the value of unserved energy are in the range of A\$40,000-100,000/MWh.<sup>23</sup> The Electricity Authority's recent Value of Lost Load (VoLL) technical report found that the value of unserved energy tends to vary by duration of outage, location and type of customer.<sup>24</sup> The Technical Report referred to a 2010 VoLL survey which found that the value (in \$/MWh) of unserved energy fell dramatically as outage duration increased from 10 minutes to 8 hours.<sup>25</sup> However, even with an 8-hour outage, the Technical Report found consumption-weighted VoLLs of:<sup>26</sup>

- \$14,900/MWh in Auckland
- \$18,690/MWh in Christchurch
- \$9,377/MWh in Taranaki.

This suggests that a lower-bound maximum willingness to pay of \$10,000/MWh would be reasonably conservative.

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<sup>21</sup> Mathematically, since the integral's upper bound is infinite in equation 20 of Dobbs' paper, it can be shown that such integral has a finite value if and only if  $\epsilon < -1$ .

<sup>22</sup> *Electricity Industry Participation Code* 2010, Schedule 12.2, clause 4.

<sup>23</sup> See, for example, Australian Energy Market Operator, *Value of Customer Reliability Issues Paper*, March 2013.

<sup>24</sup> Electricity Authority, *Investigation into the Value of Lost Load in New Zealand, Report on methodology and key findings*, 23 July 2013 (Technical report).

<sup>25</sup> Technical report, Tables 11 and 12, pp.37-38.

<sup>26</sup> Technical report, Tables 1 to 3, pp.2-3.

### 3.1.3 Demand served by existing and new investment

Dobbs' model separates demand into two categories: demand served by existing investment; and demand served by new investment. We assumed all new investments are deferrable, as this seems to be appropriate for most electricity network investments. In his examination of "mixture of investment" in table 3 of his original paper, Dobbs also considered only new investments that are deferrable.

Dobbs' model calculates welfare over time. At any given time,  $t$ , the demand function for category  $i$  in Dobbs' model takes the form

$$Q_{t,i} = B_i e^{\alpha_i t} P_i^{\epsilon_i}$$

To obtain the 'height' ( $B$ ) of the demand curve served by Transpower's existing investment, we used New Zealand calendar year 2012 retail demand and *volume-weighted* average price<sup>27</sup> as the starting point.<sup>28</sup> In that year, the total retail demand across industrial, commercial and residential sectors was 38.85 TWh. The volume-weighted average retail price across the three sectors was \$186.77/MWh in real 2013 New Zealand dollars.<sup>29</sup>

The concept of "demand served by new investment" can be ambiguous in the electricity market. This is because unlike many other industries, new investments in electricity network typically do not lead to goods and services that are physically different from existing investment. In our modelling, we treat "demand served by new investment" as demand that would be left unserved if investment in distribution and transmission networks were reduced. They include:

- Network investment at new locations. An example for this would be a new factory opening at a new connection point.
- Network investment at an existing location due to increased demand for network capacity. An example for this would be fast population growth in a suburb.

A higher proportion of demand served by new investment relative to existing investment will lead to a higher optimal WACC percentile. This is because the

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<sup>27</sup> This is the most recent year where retail demand and price information, published by the Ministry of Business, Innovation and Employment, can be found for all industrial, commercial and retail sector. See <http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/electricity> and <http://www.med.govt.nz/sectors-industries/energy/energy-modelling/data/prices>. Data were accessed on 31<sup>st</sup> July 2014.

<sup>28</sup> The parameter  $B$  can then be worked out by substitute the starting point  $P$  and  $Q$  and the relevant elasticity.

<sup>29</sup> In more disaggregated terms, the average retail prices were \$105.7/MWh for industrial, \$171.9/MWh for commercial and \$268.0/MWh for residential.

total loss in welfare from such ‘new demand’ is larger in the event of delay in new investment.

A precise, bottom-up approach to forecasting new demand would require not only an engineering and power system study of the transmission and distribution network, but relevant financial and regulatory analysis as well. Such an exercise would be complex and inevitably subjective. Hence, we infer the demand for new investment from Transpower’s capex information instead. Transpower’s data suggest that the ratio of its capex to RAB is roughly 5% and the ratio of its grid capex to grid replacement cost is roughly 2%. For the base case, we assumed demand served by new investment is 1% of that served by existing investment. This is lower than the capex ratios quoted above. We made this rather conservative assumption to take into account the fact that the electricity networks are not always utilised at their full capacity. Our assumption implies that at the starting point of the new demand curve, the price is \$186.77/MWh and the quantity is 0.39 TWh, which is about 44MW in terms of average load. This is significantly more conservative than the assumptions adopted in Dobb’s original paper, where the lowest proportion of demand served by new investment is 5% of total demand.<sup>30</sup> We assumed that both existing and new demand curves exhibit the same elasticity.

### 3.1.4 Growth

In recent years New Zealand has experienced a gradual decline in electricity consumption<sup>31</sup> and a flattening of peak demand growth due to various factors such as energy efficiency initiatives and demand side management. This trend suggests that the future growth rate in annual energy (TWh) is likely to be weak. Therefore, we assume that the growth rate for demand served by existing investment (TWh) is 0% in our modelling.

For demand served by existing investment, a higher growth rate will lead to a lower optimal WACC. This is because the risk of underinvestment is absent with sunk assets. Therefore, a higher growth rate of existing demand means the deadweight loss from a price increase is unambiguously larger. Given the recent *declining* trend in New Zealand electricity consumption, our assumption of 0% growth is conservative. Had we adopted a negative growth rate for such ‘existing demand’, the optimal WACC would be even higher.

It is difficult to precisely forecast the growth rate for demand served by new investment for the same reason as in the previous section. We used Transpower’s

<sup>30</sup> Table 3 of Dobb’s paper presents the numbers as “proportion of new investment to total investment”. The third paragraph of page 20 further explains the proportions come from the parameter B, which is the measure of split of demand served by each category.

<sup>31</sup> Ministry of Business, Innovation and Employment, *New Zealand’s Energy Outlook: Electricity Insight*, 2013



peak demand forecast in its 2014 Annual Planning Report<sup>32</sup> as a proxy and assumed that new demand grows by 1% every year. However, we also tested a 0% growth figure and obtained similar results (see section 4.2, footnote 37).

The effect of growth in new demand on the optimal WACC is ambiguous. With a higher growth rate, the deadweight loss from an increase in price is larger, *conditional on investment occurring*. However, in the case of a *delay in investment*, the loss in the entire surplus is also bigger. The overall impact depends on other parameter inputs as well as the magnitude of change. We have conducted several test simulations (not reported here) by assuming slightly different demand growth rates. The effect on the base case optimal WACC percentile is negligible.

## 3.2 Price pass through

End-use electricity customers pay for network services as part of the overall tariff for delivered energy. Hence, the demand for network conveyance is derived from the demand for delivered electricity.

Our model assumed that the regulated WACC percentile affects both electricity transmission and distribution activities. The relationship between the final regulated network price  $\hat{p}$  and the regulated WACC  $\hat{r}$  is given by

$$\hat{p} = c + (\gamma + \hat{r})K$$

Where  $c$  and  $K$  are the variable and upfront capital cost measured in \$/MWh and  $\gamma$  is the annual rate of depreciation (see section 3.4.) In our simulation, we modelled transmission and distribution network together. This was motivated by the fact that: (1) their regulated WACCs often move together very closely; and (2) their regulated prices both form part of the final retail tariff.

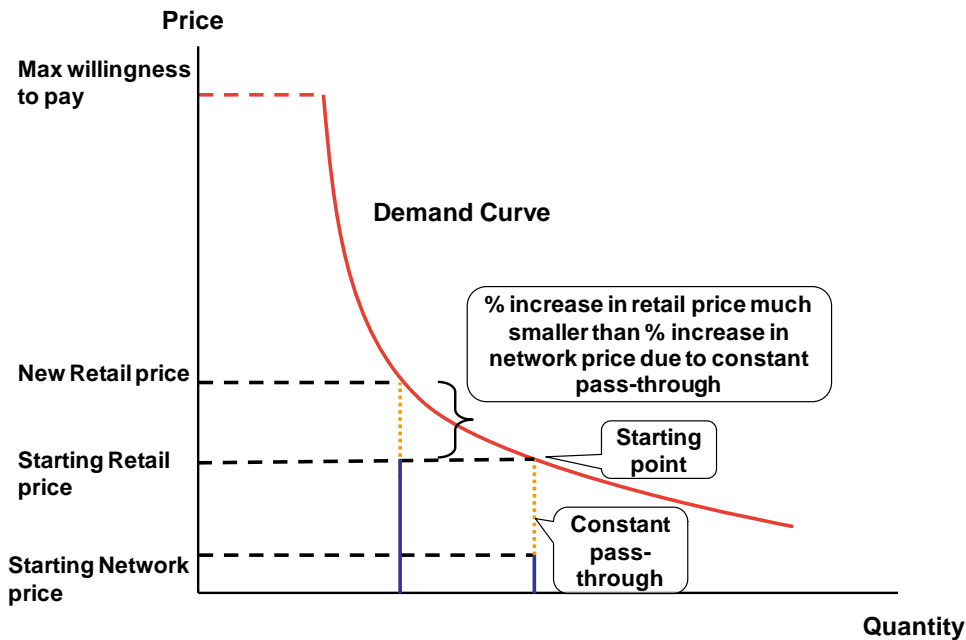
We modelled *final retail* demand because the own-price elasticity of demand is only available in relation to delivered electricity. We estimated that transmission and distribution prices represent 11.76% and 23.93%, respectively, of the final *volume-weighted average* retail price across the industrial, commercial and residential sectors.<sup>33</sup> This implies that at the ‘starting point’ on the demand curve, the volume-weighted average price is  $186.77 \times 11.76\% = \$21.96/\text{MWh}$  for transmission and  $186.77 \times 0.22 = \$44.69/\text{MWh}$  for distribution. The remaining  $\$120.11/\text{MWh}$  was treated as a constant pass-through to the final retail price when the regulated transmission and distribution price changes in our simulation. Figure 1 illustrates the demand function and the treatment of pass-through.

<sup>32</sup> Transpower, *Annual Planning Report*, 2014

<sup>33</sup> These figures were estimated using demand and price information in footnote 27, and network revenue data supplied by Transpower.



Figure 1: Illustration of demand function and the impact of an increase in network price on final bill



Source: Frontier Economics

The assumption that transmission and distribution prices both change in response to changes in the allowed rate of return leads to a conservative estimate of the optimal WACC. Since other components of the retail price are held constant, a 1% increase in network price causes the final retail price to rise by much less than 1%. In other words, the *implied effective* elasticity of demand with respect to transmission and distribution prices is much less than the elasticity of demand with respect to the final retail price. Had we only modelled the transmission sector and held distribution prices constant as a pass-through, our modelling would have yielded an even lower *effective* elasticity and consequently a higher optimal WACC.

### 3.3 WACC distribution

We used the latest vanilla WACC estimate in the Commerce Commission's July 2014 determination as the basis for our assumed WACC distribution.<sup>34</sup> That is, we assumed that the true WACC is normally distributed with a mean/mid-point of 6.83% and a standard deviation of 1.067%. We truncated our simulation at  $\pm$

<sup>34</sup> Commerce Commission, Cost of capital determination for information disclosure year 2015 for Transpower, gas pipeline businesses and suppliers of specified airport services (with a June year-end) [2014] NZCC 19, 31 July 2014.

4 standard deviations. Given a normal distribution, there is very little truncation in practice.

### 3.4 Cost, depreciation and regulatory length

We assumed that the annual rate of depreciation is 2.5% in our model, based on a straight-line approach to depreciation over 40 years. Consistent with the New Zealand practice, the assumed regulatory length in our model is five years.

In the base case scenario, we also assumed that 70% of transmission and distribution prices reflect the businesses' fixed cost and the remaining 30% are variable. Using the same notation from Dobbs' model, this means the variable cost,  $c$ , is \$6.59/MWh for transmission and \$13.41/MWh for distribution. Since the mean of the assumed WACC distribution is 6.83%, one can infer the upfront capital cost for transmission networks in \$/MWh as follows:

$$K = \frac{0.7 \times 21.96}{(2.5\% + 6.83\%)} = \$164.73$$

The above equation follows because the model uses continuous discounting over an infinite time horizon. Similarly, for distribution networks, the capital cost is \$335.26/MWh.<sup>35</sup>

A higher proportion of fixed cost, *ceteris paribus*, implies a higher upfront capital cost  $K$ . Thus a given increase in WACC leads to a larger increase in price and larger deadweight loss. As a consequence, the optimal WACC is lower with a higher proportion of fixed cost.

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<sup>35</sup> Dobbs' original approach directly assumes a variable and upfront capital cost. In our case they are inferred from the current transmission and distribution prices. We adopted the current approach because transmission and distribution are only part of the final retail price and we also need to estimate the remaining pass-through. Dobbs' original model does not have this feature.

## 4 Results

### 4.1 Base case scenarios

Our base case simulation shows that the optimal WACC is at the 99<sup>th</sup> percentile of the distribution (if a total welfare standard is applied). One of the key reasons why our optimal WACC percentile is higher than Dobbs' original results is the inelastic nature of electricity demand, as compared to the elastic demand assumptions incorporated in the Dobbs model. The assumed elasticity of -0.3 under our base case is not as high (in absolute terms) as the most elastic estimate used by the Australian Productivity Commission (-0.7); but nor is it as low as the Productivity Commission's lower bound estimate (-0.2) or the Electricity Authority's estimate of -0.01. Further, as discussed above, the fact that network prices only constitute approximately one-third of the final retail tariff faced by consumers means the *implied* demand elasticity with respect to network prices is actually much smaller than the assumed value. Thus, the loss in welfare due to allocative inefficiency is very modest compared to that from curtailed investment.

### 4.2 Sensitivity using alternative scenarios

Given there are uncertainties around the input parameters, we have also investigated two alternative input scenarios, where the alternative inputs are plausible given our discussions in Section 3. The input parameters are chosen for each scenario such that, *everything* else held constant:

- the change of each parameter under Scenario 1 should, *a priori*, lead to a higher optimal WACC percentile than under the base case; and
- the change of each parameter under Scenario 2 should, *a priori*, lead to a lower optimal WACC percentile than under the base case

The inputs used in each scenario are presented in Table 3.

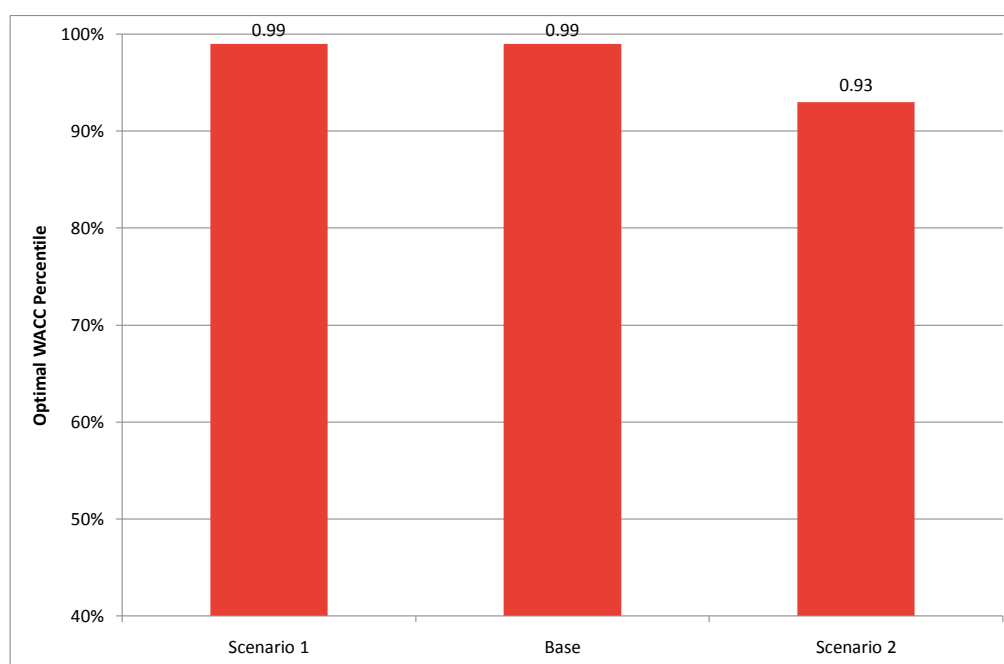
Table 3: Alternative input scenarios

Parameter	Scenario 1	Scenario 2
Demand served by new investment (at starting point on demand curve)	1.5% of existing =0.58 TWh	0.5% of existing =0.19 TWh
Elasticity of demand	-0.1	-0.7
Maximum Willingness to Pay	\$50,000/MWh	\$10,000/MWh
Network fixed cost component	65%	75%

Source: Frontier Economics

The results of simulation the simulation analyses are presented in Figure 2. Given that the base case scenario already results in the 99<sup>th</sup> percentile, the fact that the optimal WACC percentile corresponds to 99<sup>th</sup> percentile under Scenario 1 is not surprising. It is worth noting that under Scenario 2, although all parameter inputs are at the very conservative end, the optimal WACC percentile is still relatively high, i.e. at the 93<sup>rd</sup> percentile. In other words, the base case result is very robust to different sets of inputs, within plausible bounds.<sup>36 37</sup>

Figure 2: Simulation results from base, High and Low WACC scenarios



Source: Frontier Economics

### 4.3 Sensitivities: extreme input scenarios

We also conducted sensitivity analyses to investigate the input parameters that would need to be adopted to generate optimal WACCs at:

<sup>36</sup> Due to the nature of the mathematical approximation within the model, the Monte Carlo simulation results can fluctuate within a few percentiles, which has no impact on the qualitative results obtained in the report. The fluctuation is due to two reasons. Firstly, there is inherently a very small amount of “lumpiness” in the mathematical approximation, which is reflected in the construction of the parameter  $r_c^*$  in equation 29 of the original paper. This number is not strictly monotonically increasing in  $\hat{r}$ . Secondly, two sets of Monte Carlo draws can result in different sets of numbers used in the simulation.

<sup>37</sup> The use of a 0% growth rate for demand served by new investment altered the numbers only slightly, to 98% for the base case, 100% for Scenario 1 and 95% for Scenario 2.

- the 70<sup>th</sup> percentile (which roughly corresponds to the 67<sup>th</sup> percentile proposed by the Commission in its Draft Decision); and
- the 50<sup>th</sup> percentiles (which corresponds to the percentile proposed by the Major Energy Users' Group).

It transpires that the parameter values required in order to achieve these optimal percentiles fall far outside the range that could reasonably be considered plausible for the electricity network industry. Some representative examples of the required changes to the base case parameters are described in Table 4.

Table 4: Inputs required to generate lower optimal WACCs

Parameter	WACC at 70 <sup>th</sup> percentile	WACC at 50 <sup>th</sup> percentile
Demand served by new investment (at starting point on demand curve)	0.1% of existing = 0.04TWh	0.05% of existing = 0.02TWh
Elasticity	-0.9	-1.5
Maximum willingness to pay	\$3,000/MWh	\$1,000/MWh
Network fixed cost component	90%	100%

Source: Frontier Economics

In view of these results, and those presented in section 4.2, we conclude that the Commission's practice of adopting the 75<sup>th</sup> percentile of its estimated WACC range is likely very conservatively low (and conservatively low on a consumer-surplus-only basis; see section 4.4) despite analysing only reliability (i.e. unserved energy) impacts.

## 4.4 Sensitivities: consumer surplus only

As noted in section 2.3, some submitters have argued that when evaluating the appropriate WACC percentile, the Commission should adopt a consumer welfare standard rather than a total welfare standard. The Commission's Draft Decision was ambivalent on the question of which welfare standard should be used in such analyses; as such the Commission considered both the consumer welfare and total welfare approaches.<sup>38</sup>

For completeness, we have run a sensitivity where the model maximises only consumer surplus and ignores entirely the effect on surpluses to producers. This

<sup>38</sup> Commission's Draft Decision, paras. 2.16 and 2.17.

would be consistent with assuming that the regulator's objective is to maximise only consumer surplus. Assuming a price rise causes a negligible reduction in consumption (e.g. in the case of very inelastic demand), the sole impact of such a change is to effect a transfer from consumer surplus to producer surplus. However the transfer is not as a welfare loss when both the consumer and producer surplus are counted towards total welfare. Including only consumer surplus as welfare in the optimisation means that, for a given price increase, such a transfer is subtracted from total welfare and hence the measured 'welfare loss' is much larger and the optimal WACC lower.

A consumer surplus only analysis will always result in a lower optimal WACC than a total surplus analysis. Employing all assumptions under our base case scenario, but optimising for consumer surplus not total surplus, the optimal WACC percentile lies at the 87<sup>th</sup> percentile.

This suggests to us that even under a consumer welfare standard, the Commission's current approach of adopting the 75<sup>th</sup> percentile is conservatively low. That conclusion would be further reinforced when account is given to the generally conservative nature of input parameters selected for the base case and the omission of avoided resource costs of generation and 'economic' (as opposed to 'reliability') investments from the analysis.

## Appendix A: Replication of Dobbs' simulation analysis

In seeking to apply Dobbs' model to the New Zealand electricity networks sector, we developed our own simulation of the model using the programming software 'R', which is widely used by quantitative researchers in many different disciplines. With this model we were able to replicate most of Dobbs' results given the parameters reported in his paper.<sup>39</sup> The only results in Table 2 of Dobbs (2011) we could not replicate precisely were those incorporating demand growths at 5% (cases 10-12 of table 2). In those cases, our model produced optimal percentile results lower than those reported by Dobbs. We corresponded with Professor Dobbs by email and were able to identify the source of these discrepancies.<sup>40</sup>

With Professor Dobbs' assistance, we found that the discrepancies arose because he had access to less computing power when he undertook the Monte Carlo modelling reported in his paper than we have at our disposal. Whilst our simulation code was written in R, Professor Dobbs' code was written in TSP, which is slower than R in performing simulations of this kind. To circumvent the shortfall in computing power, Professor Dobbs employed a computation technique different from ours.

Both ours and Professor Dobbs' simulations involved making 1 million random draws from a truncated normal distribution. This 1 million draw represents the uncertainty in the firm's WACC distribution when the regulator sets the regulated WACC. In working out the expected welfare, we followed the description in Professor Dobbs' paper by calculating the *ex-post* welfare against *every* observation from the 1 million draw. The same exercise would be extremely time-consuming in Professor Dobbs' software, TSP. As a shortcut, Professor Dobbs calculated the mid-points of the 100 percentiles from the 1 million random draws by averaging the 10 thousand observations within each percentile. He then calculated the *ex-post* welfare against such 100 midpoints.

This shortcut, made out of necessity due to the constraints imposed by computing power, is harmless in most of Professor Dobbs' simulation where demand growth is at 0%. However, in cases 10-12 of his table 2, Professor Dobbs used a demand growth rate of 5%. This also happens to be the lower

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<sup>39</sup> There are occasionally minor differences of  $\pm 1$  percentile in the final results. But this is mainly due to the accuracy of the Monte Carlo simulation.

<sup>40</sup> We are extremely grateful that Professor Dobbs very promptly replied our queries and was generous in sharing his source code with us so that we were able to quickly identify the source of the discrepancy.

bound of the WACC distribution for the Monte Carlo simulation. The right-hand-side of his original paper takes the form of

$$\frac{1}{n} \sum_i^n \frac{1}{(r_i - \alpha)}$$

Where  $n = 1 \text{ million}$  and  $r_i$  is a random draw  $i$ . When  $\alpha$  is 5%, the denominator of this expression approaches 0 for those  $r_i$  that are close to the lower bound (5%) of the WACC distribution. Consequently, the values of the expression above are very large for those  $r_i$ . By averaging out the 10 thousand observations in each percentile, Professor Dobbs' midpoint approach inadvertently caused significant underestimation of the expression above for those random draws at the lowest several percentiles of the distribution.<sup>41</sup>

It needs to be noted that when investment is not sunk, the optimal WACC is still much higher than the 50<sup>th</sup> percentile. In the case of deferrable investment with elasticity of -1.5, the optimal WACC is at the 85<sup>th</sup> percentile.

Table 5 below reports revised results for cases 10, 11 and 12 having corrected for the error in the original model.

Table 5: Updated results for 5% demand growth cases

Case	Optimal WACC percentiles		
	Category 1 (Sunk)	Category 2 (Non-deferrable)	Category 3 (Deferrable)
10 (Elasticity -1.5)	44 <sup>th</sup> (Original)	77 <sup>th</sup> (Original)	91 <sup>st</sup> (Original)
	34 <sup>th</sup> (Revised)	63 <sup>rd</sup> (Revised)	85 <sup>th</sup> (Revised)
11 (Elasticity -3)	44 <sup>th</sup> (Original)	73 <sup>rd</sup> (Original)	91 <sup>st</sup> (Original)
	34 <sup>th</sup> (Revised)	61 <sup>st</sup> (Revised)	78 <sup>th</sup> (Revised)
12 (Elasticity -6)	43 <sup>rd</sup> (Original)	68 <sup>th</sup> (Original)	79 <sup>th</sup> (Original)
	34 <sup>th</sup> (Revised)	57 <sup>th</sup> (Revised)	70 <sup>th</sup> (Revised)

Source: Dobbs (2011), *Frontier Economics*.

<sup>41</sup> This is a well known result called "Jensen's inequality" which states that for a strictly convex function  $f(x)$ ,

$$\frac{1}{n} \sum_i^n f(x_i) > f\left(\frac{1}{n} \sum_i^n x_i\right)$$



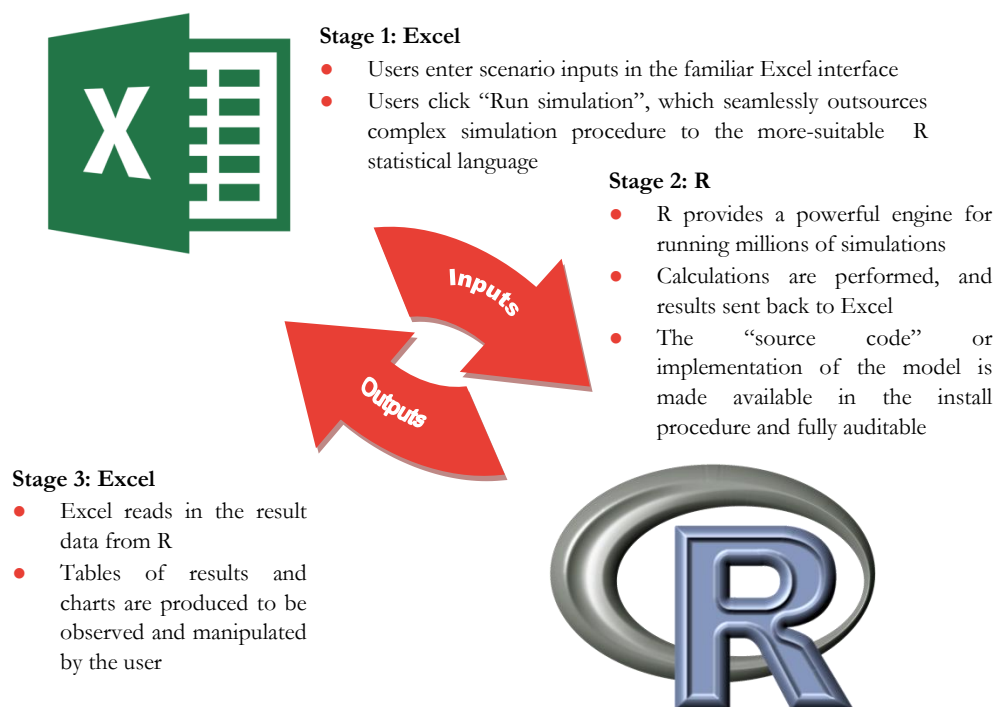
## Appendix B: Frontier's model implementation

This appendix provides more detail into Frontier's user-friendly version the loss function simulation model. There are two key elements that make up the model, although casual users would only be exposed to the first:

- The **user interface** is a Microsoft Excel workbook which facilitates users modifying input scenarios, triggering model runs, and viewing and manipulating results.
- The **model engine** is written in the R statistical programming language, a common choice in the world of statistics and data analysis. We did not use Excel as it is not well suited to the type of data manipulation and calculation procedures required by the methodology. The “source code” (full details of the inner workings of the model) is made available as part of the install procedure and is fully auditable.

Figure 3 presents a schematic of the operation of the model.

Figure 3: Schematic of model operation



Source: Frontier Economics

The model “package” provided to users of the model includes:

- An Excel workbook containing the user interface, including sample data with corresponding results
- An **installer** file that installs and configures all necessary software required to run the model (other than Excel)
- **User documentation** describing how to install and use the model, and (in brief terms) how to audit the workings of any part of the model.

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