A Supplementary Note on Measurement Error and Regulated Firms' Allowed Rates of Return

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1 Introduction

1. I have previously been engaged by Transpower New Zealand Limited to review the material on the cost of capital in the Commerce Commission's "Draft Reasons Papers" released as part of the Input Methodologies project, with a particular focus on how the Commission should deal with measurement error in its estimates of Transpower's cost of capital. This work resulted in a paper entitled "Measurement Error and Regulated Firms' Allowed Rates of Return", which was submitted to the Commission by Transpower (Guthrie, 2010). Transpower has now requested that I review the paper by Officer and Bishop (2010), and examine its implications for my earlier work, in the context of the Revised Draft Commerce Act (Transpower Input Methodologies) Determination 2010 (referred to as the "Revised Draft Determination" below).

2. I am providing my advice in accordance with the Code of Conduct for expert witnesses contained in the High Court Rules, and my curriculum vitae is attached as an appendix to this report. I do not comment on all issues relating to the Input Methodologies project and no inference should be drawn concerning my views on matters on which I do not comment.

2 Placing the Officer-Bishop and Guthrie submissions in context

3. The Commission has recognised that the costs to society associated with errors in measuring regulated firms' cost of capital are asymmetric.[1] Specifically, if Transpower's allowed rate of return is lower than its cost of capital then it will not be able to recover the full costs associated with its investment programme, leading to under-investment by Transpower and creating a relatively large welfare loss. In contrast, if the allowed rate of return is greater than Transpower's cost of capital then, while Transpower will have no incentive to under-invest, consumers will end up paying too much for Transpower's services; this creates a relatively small welfare loss.

[1] See, for example, para 59 of the Commission's *Revised Draft Guidelines: The Commerce Commission's Approach to Estimating the Cost of Capital*, where it states that "[a]s a general principle, the Commission considers that the social costs of setting allowed returns too low likely outweigh the social costs of setting them too high."

Average welfare losses can be minimized by setting the allowed rate of return at some point above the midpoint of the range of plausible values, since this reduces the probability of the relatively large welfare losses from under-investment, at the cost of increasing the probability of the relatively small welfare losses from overcharging.

4. This has motivated the Commission to decompose its calculation of Transpower's allowed rate of return into two parts.

   - **Mid-point estimate:** First, it calculates a "mid-point estimate" of Transpower's weighted-average cost of capital (WACC), using the approach specified in Sections 3.5.1-3.5.4 of the Revised Draft Determination. The Commission calculates the mid-point estimate using a series of mathematical formulae that yield a theoretical estimate of Transpower's cost of capital from various parameters. Some of these parameters (such as the tax rate) are observable, but most (for example, a measure of the risk associated with Transpower's business, known as the "asset beta") are unobservable and must be estimated from data on quantities such as stock returns.
   - **Measurement-error adjustment:** Second, the Commission calculates an increment to reflect the asymmetric social costs of measurement error, using the approach described in Sections 3.5.5-3.5.7 of the Revised Draft Determination. The Commission adds this increment to the mid-point estimate to obtain Transpower's allowed rate of return. The appropriate adjustment is largest in situations where there is likely to be the largest measurement error. The Commission has decided to calculate this adjustment using another series of mathematical formulae, which gives a theoretical estimate of the likely magnitude of the measurement error (referred to as the "standard error" of the WACC) in terms of various parameters that the Commission estimates.

5. The Officer and Bishop (2010) and Guthrie (2010) submissions on behalf of Transpower each focus on a separate part of this calculation.

   - Officer and Bishop (2010) evaluate the Commission's calculation of the mid-point estimate of Transpower's WACC and set out their own calculation of this quantity. Officer and Bishop obtain different values for the mid-point estimate from the Commission because they make different assumptions regarding the parameters that are input into the series of mathematical formulae. They adopt the Commission's approach to calculating the measurement-error adjustment.
   - Guthrie (2010) uses the Commission's value for the mid-point estimate and focusses instead on evaluating the Commission's calculation of the measurement-error adjustment and augmenting it to better capture the measurement error associated with the Commission's calculations. I obtain different values for the measurement-error adjustment from the Commission because I use a more sophisticated approach to calculating the magnitude of measurement error and because I do not make several of the Commission's simplifying assumptions.

6. Although we investigated the two components of the allowed rate of return separately in our original submissions, the calculations of the two parts should be performed together since they share some common parameters. For example, both the mid-point estimate and the measurement-error adjustment depend on the maturity adopted for the risk-free interest rate. Since Officer and Bishop use a different maturity from the Commission, my analysis of the measurement-error adjustment appropriate for the Commission's mid-point estimate is not directly applicable to the Officer-Bishop mid-point estimate. Therefore, in this submission I implement my method for calculating the measurement-error adjustment using the parameter values and assumptions adopted in Officer-Bishop. This provides a more complete picture of the implications of the analysis in Guthrie (2010) and Officer and Bishop (2010).

3 Understanding the measurement-error adjustment

7. In my original submission I explained that Transpower's cost of capital at an arbitrary date within the five-year regulatory cycle can be expressed as the sum of four terms:[2]

   - The Commission's **mid-point estimate** of Transpower's WACC.
   - The **statistical error** associated with the estimated WACC at the start of the current regulatory cycle. This error arises because some of the inputs into the Commission's formulae are essentially random variables. For example, the estimate of the "equity beta" of a firm is the slope of the "line of best fit" on a graph showing returns of the firm's shares on one axis and returns on a diversified portfolio on the other axis. These two returns evolve unpredictably, so that the slope of the line of best fit varies with the particular set of returns. The particular sample used to estimate the equity beta may have an unusually steep relationship in one case and an unusually flat relationship in another. In the first case, the estimated equity beta will be higher than the true value; in the second case the estimated equity beta will be lower than the true value. Since many of the inputs into the WACC calculation exhibit such sampling variation, the output—that is, the mid-point estimate of Transpower's cost of capital—will also exhibit sampling variation. This variation is what we mean by the statistical error associated with the cost of capital estimate.
   - **Intra-cycle variation** in Transpower's actual cost of capital since the start of the current regulatory cycle. This arises because the Commission's estimate of Transpower's cost of capital is being held constant throughout the entire five years of each regulatory cycle, while the factors that determine the actual cost of capital—such as the levels of New Zealand and overseas interest rates and risk premia—fluctuate throughout the period. Even if the Commission was able to measure Transpower's cost of capital perfectly at the start of the regulatory cycle (and it is not able to do so), the inevitable fluctuation in Transpower's cost of capital over the ensuing five years would introduce a wedge between the Commission's estimate of the cost of capital and Transpower's actual cost of capital.

[2] See para 14-21 of Guthrie (2010).

- **Model error**, which is caused by factors that affect Transpower's actual cost of capital not being incorporated in the simple theoretical model known as the CAPM. The classical form of the CAPM, as well as the modification used by the Commission, predicts that the only aspect of a firm's risk that affects the expected rate of return required by investors is so-called "systematic risk", which is the component of the firm's net cash flows that is correlated with the return on the "market portfolio" (the hypothetical portfolio made up of all risky assets available to investors) and is measured by the quantity known as "beta". However, there is extensive empirical evidence showing that other factors also affect investors' required rates of return. Such factors include (but are not limited to) various ratios involving share prices, earnings, asset market values, and asset book values.[3]

8. Officer and Bishop (2010) deal with the first of these four terms, whereas my original submission deals with the remaining three.

9. Since the sum of the four terms is Transpower's actual cost of capital, and the first term is the Commission's mid-point estimate of its cost of capital, it follows that the sum of the three remaining terms is the measurement error. That is,

$$\text{measurement error} = \text{statistical error} + \text{intra-cycle variation} + \text{model error}$$

   equals the difference between the Commission's mid-point estimate of the cost of capital and Transpower's actual cost of capital.

10. Measurement error is a random variable. When we refer to its "75th percentile" we mean the number such that the probability that the measurement error turns out to be less than this number is 75% and the probability that it turns out to be greater than this number is 25%. Similarly, the 90th percentile is the number such that the measurement error turns out to be less than this number with probability 90% and greater than this number with probability 10%.

11. As I show in my original submission (para 7–10 of Guthrie (2010)), if the 75th percentile is chosen as the measurement-error adjustment then, when viewed from the start of each regulatory cycle, in 25% of the situations in which a firm might try to raise capital during the forthcoming cycle, that firm will face a cost of capital that exceeds its allowed rate of return; that is, in 25% of cases, the firm will want to under-invest. This would seem to lead to considerable under-investment and in my opinion a higher percentile might be appropriate, especially given the new purpose statement from Part 4 of the Commerce Act 1986, which notes that regulated firms should "have incentives to innovate and to invest, including in replacement, upgraded, and new assets" (s.52A(1)(a)). For example, if the Commission adopted the 90th percentile then in only 10% of cases would the firm have an incentive to under-invest. In my calculations below, I therefore report the measurement-error adjustments that correspond to the 75th and 90th percentiles.

12. Of the three components making up the measurement error associated with the Commission's cost of capital estimate, the Commission makes an allowance for only one. Specifically, the

[3] See Fama and French (2004) for a review.

Commission allows for statistical error, but it makes no allowance for model error and completely ignores intra-cycle variation in Transpower's cost of capital. Furthermore, as I explained in my original submission, the Commission does not calculate the allowance for statistical error appropriately, partly because it does not calculate the standard errors of the inputs to its WACC calculation correctly, and partly because it does not combine the individual standard errors correctly.[4]

13. The adjustments for statistical error and intra-cycle variation are reasonably straightforward to estimate, as I demonstrated in my original submission. The magnitude of model error is much more difficult to quantify. Indeed, I am not aware of any formula that allows it to be calculated. However, we do know that the magnitude of model error is not zero and that setting it equal to zero (which is what the Commission implicitly does) will underestimate its true value. This will in turn lead the Commission to underestimate the appropriate measurement-error adjustment, which will lead to under-investment occurring more often than is implied by the chosen percentile. For example, if the Commission uses the 75th percentile, the probability of under-investment will be larger than 25%, potentially by a substantial margin.

14. I discuss these issues in more detail below. First, I use the method in my original submission to calculate the measurement-error adjustment that correctly reflects statistical error and intra-cycle variation. Second, I discuss various sources of model error, especially as they relate to Transpower's particular circumstances.

4 Measurement-error adjustment for Commission and Officer-Bishop mid-point estimates

15. In this section I calculate the measurement-error adjustments to the mid-point estimate of the Commission's so-called "vanilla WACC".[5] My analysis in this section focusses solely on the adjustment due to statistical error and intra-cycle variation. I carry out the exercise using two sets of assumptions regarding the mid-point estimate: first, the Commission's assumptions (as described in Officer and Bishop (2010)); second, the assumptions used by Officer and Bishop themselves. These are summarized in the first table of Officer and Bishop (2010). There are four key differences between the two approaches:

    - The Commission assumes leverage of 40%, whereas Officer and Bishop assume leverage of 60%.

[4] For example, with respect to the asset beta, the Commission states that it calculates one thing ("the standard error...of the average asset beta") but calculates something else (Guthrie, 2010, para 23.2); it assumes that leverage is measured with perfect accuracy when that is not the case (ibid., para 46-50); and it uses a deeply flawed methodology to calculate the standard error of the market risk premium (ibid., Appendix C).

[5] My original submission carried out this exercise for the post-tax WACC, using the Commission's assumptions underlying its calculations of the mid-point estimate.

- The Commission assumes that the risk-free rate has a maturity of five years, whereas Officer and Bishop assume a maturity of ten years.[6] In the specific example developed by Officer and Bishop, the five-year rate is 4.70% and the ten-year rate is 5.48%.
- The Commission assumes a (tax-adjusted) market risk premium of 7%, whereas Officer and Bishop assume one of 9.53%.
- The Commission assumes an equity beta of 0.57, whereas Officer and Bishop assume one of 0.70.

16. In order to calculate the measurement-error adjustment, I need to choose values for several parameters that measure the magnitude of statistical error in individual inputs to the WACC calculation, as well as the magnitude of intra-cycle variability. When calculating the measurement-error adjustment for the Commission's WACC estimate, I choose values derived in Guthrie (2010).[7] When dealing with Officer and Bishop (2010), I make appropriate modifications to the assumptions in my original submission:

    - Because Officer and Bishop use the ten-year rate as the risk-free rate—and the ten-year rate is less volatile than the five-year rate—the intra-cycle variability in Transpower's cost of capital will be smaller. When I carried out the exercise described in para 58 of my original submission, I calculated that the standard error of the five-year risk-free interest rate is 1.06%. When I repeat this exercise for the ten-year risk-free interest rate, I calculate that the standard error is 0.83%. In my calculations below, for the Commission case I use a risk-free interest rate of 4.70% with a standard error of 1.06% and for the Officer-Bishop case I use a risk-free interest rate of 5.48% with a standard error of 0.83%. That is, the longer-term rate is higher, but less volatile.
    - Officer and Bishop use leverage of 60%, which I understand is much closer to Transpower's actual leverage than the figure of 40% used by the Commission for all of the firms that it regulates. As I explained in Guthrie (2010, Section 4.2), when using a single leverage figure for all firms it is necessary to recognise that this economy-wide figure will most likely be inappropriate for any particular firm. Thus, there will be a wedge between a firm's actual leverage and the level estimated by the Commission. I therefore assumed that an individual firm's leverage parameter was normally distributed with an average of 40% and standard deviation of 11%, where the latter figure was estimated from the Commission's sample of firms in the electricity sector. I retain that assumption here when considering the Commission's mid-point estimate. In contrast, I am interpreting the 60% figure used by Officer and Bishop as being much closer to Transpower's actual leverage and so

[6] The Commission actually uses two different maturities in two different parts of its calculations. It uses the five-year rate where the risk-free rate appears directly and the ten-year rate where it appears indirectly in the market risk premium. Along with many other external experts, I have highlighted the inconsistency in this approach and advocated that the Commission adopts a single maturity when it uses the CAPM. See, for example, paras 23-30 of Boyle et al. (2006).

[7] I used four slightly different approaches to estimate one parameter (the standard error of Transpower's beta) in my original submission. As Table 3 of that submission shows, the approaches lead to almost identical results. Therefore, for the calculations here I use just one of those approaches (based on the distribution of the estimated equity betas for all comparison firms used by the Commission for its own analysis). My final results are not sensitive to this choice.

I assume an average of 60% and standard deviation of 0% when considering the Officer-Bishop mid-point estimate.[8]

- I argued in my original submission that the Commission's approach to calculating the standard error of its asset beta estimate is unclear. I demonstrated one approach to estimating the standard error, and calculated a value of 0.12. I continue to use that value here.
- I explained in my original submission why I believe the Commission's value for the standard error of its market risk premium (MRP) estimate is unreliable. I proposed a much simpler and far more conventional approach to calculating this standard error and I continue to use those estimates here.

17. As in my original submission, I consider several different scenarios, that vary according to (i) the precision with which we can estimate the market risk premium and (ii) the probability of under-investment that the Commission is willing to tolerate.

18. I consider three scenarios with respect to the accuracy of the market risk premium:

    - Optimistic scenario: the standard error of the estimate of the MRP equals 30% of the point estimate of the MRP.
    - Typical scenario: the standard error of the estimate of the MRP equals 34% of the point estimate of the MRP.
    - Pessimistic scenario: the standard error of the estimate of the MRP equals 45% of the point estimate of the MRP.

19. These scenarios are motivated in Section 4.3 of Guthrie (2010). Dimson et al. (2006) report estimates of the MRP for 17 countries for the period 1900-2005, along with measures of estimation error (specifically, standard errors) for each country. There is substantial variation across the countries in both the estimates of the MRP and the precision of the estimates. A quarter of the countries in Dimson et al.'s sample have MRP estimates that are more precise than my "optimistic" scenario, where I am measuring precision here as the ratio of the standard error of the estimate to the level of the estimate (with low values of this ratio indicating greater precision). A quarter of the countries have MRP estimates that are less precise than my "pessimistic" scenario, and the median level of precision in Dimson et al.'s sample is equal to my "typical" scenario. In view of the current uncertainty in financial markets, and the difficulty in measuring the MRP that this uncertainty implies, the "pessimistic" scenario seems the most appropriate.

20. I consider two scenarios with respect to the probability of under-investment. In the first scenario, corresponding to use of the 75th percentile, the probability that Transpower will be under-compensated is 25%. In the second scenario, the probability that Transpower will be under-compensated is 10%.

[8] In reality, of course, Transpower's leverage will not equal 60% exactly, so there is still some statistical error in the Officer-Bishop estimate. Thus, my assumption that leverage has standard deviation of zero (that is, that Transpower's true leverage is exactly 60%) is conservative. The correct measurement-error adjustment will be larger than the value that I calculate below, although I expect the difference to be small.

21. The table below shows the results of implementing these calculations for the two sets of assumptions (Commission and Officer-Bishop), the three scenarios regarding the precision of the MRP estimate (optimistic, typical, and pessimistic), and the two scenarios regarding the probability of under-compensation (25% and 10%). Each entry in the table gives the measurement-error adjustment that should be applied to the mid-point estimate in order to deal with statistical error and intra-cycle variability. Allowing for model error would increase these results, perhaps substantially.

	Commission		Officer-Bishop	
Probability of under-compensation	25%	10%	25%	10%
Optimistic MRP accuracy	0.96%	1.81%	0.90%	1.68%
Typical MRP accuracy	0.99%	1.88%	0.94%	1.76%
Pessimistic MRP accuracy	1.10%	2.08%	1.08%	2.02%

Note: The entries in the table assume that the risk-free interest rate has standard error of 1.06% (for the Commission) or 0.83% (for Officer-Bishop), leverage has standard error of 11% (Commission) or 0% (Officer-Bishop), the asset beta has standard error of 0.12 (both cases), and the ratio of the MRP's standard error to its point estimate equals 0.30 (optimistic), 0.34 (typical), or 0.45 (pessimistic).

22. These adjustments should be added to the mid-point estimates of the vanilla WACC reported on p2 of Officer and Bishop (2010). That is, the numbers in the first two columns should be added to the Commission's mid-point estimate of 7.5%, whereas those in the last two columns should be added to the Officer-Bishop mid-point estimate of 9.3%. Although the Officer-Bishop mid-point estimate is larger than the Commission's, the corresponding measurement-error adjustment is slightly smaller. There are three main contributors to the reduced measurement-error adjustment.

    - First, Officer and Bishop use the ten-year risk-free interest rate rather than the five-year rate, and the lower variability of the longer-term rate means there is less intra-cycle variation in their cost of capital.
    - Second, because Officer and Bishop use an estimate of Transpower's actual leverage level, rather than an estimate of some industry-wide level as adopted by the Commission, there is less statistical error in measuring the leverage parameter.
    - Third, the estimate of the cost of capital is a weighted average of the cost of debt and the cost of equity. The use of higher leverage by Officer and Bishop means that the cost of capital depends more on the cost of debt and less on the cost of equity, and the former is measured more accurately than the latter.

23. In this submission, as in my original one, I am focussing on the size of the measurement-error adjustment that will have the socially-desirable effect on Transpower's incentive and ability to invest. I am not making any recommendation about what level of the mid-point estimate is appropriate. However, as the table above demonstrates, the appropriate level of the measurement-error adjustment is largely independent of the choice between the mid-point

estimates derived by the Commission and Officer-Bishop. This reflects the fact that Officer and Bishop face the same challenge as the Commission when they estimate Transpower's cost of capital: some measurement error is unavoidable, no matter what parameter choices are made.

24. As in my original submission, the analysis here suggests that (before any allowance for model error) if the Commission wants to ensure that the probability that Transpower is allowed to earn less than its cost of capital is 25% then the Commission should add an increment to its point estimate in the range 0.9-1.1%. If the Commission wants to reduce the probability of under-compensation (and hence under-investment) to 10%, the increment should be in the range 1.7-2.1%. This adjustment would be required even if the Commission were to adopt the mid-point estimate calculated in Officer and Bishop (2010).

5 Model error

25. The calculations reported in the preceding section give my estimate of the measurement-error adjustment that is appropriate for Transpower, given the statistical error and intra-cycle variation in Transpower's cost of capital. A further increment needs to be added to this adjustment to reflect model error. This is difficult, if not impossible, to quantify with the same level of rigour as the adjustments for statistical error and intra-cycle variation. The Commission is appealing to this difficulty in order to justify its decision to make no allowance for model error when it calculates the measurement-error adjustment to its mid-point estimate.[9] However, the issue of model error is real and in my opinion it is likely to have a material impact. In particular, model error has the potential to lead to substantial under-investment if it is not incorporated in the cost-of-capital calculations, as I discuss in this section.

26. The Commission's approach of allowing Transpower to earn a rate of return equal to the cost of capital estimate implied by a form of the CAPM rests on two theoretical pillars for its justification.

27. First, a firm's owners must all agree that management should adopt policies that maximize the market value of the firm. This implies that a firm would invest in a project only if the value to the firm's owners of the firm *with* the project is greater than or equal to its value to them *without* the project. If some additional (and very restrictive) assumptions also hold, then this implies that the firm will invest if and only if the value of the completed project is greater than or equal to the cost of acquiring or constructing the project in the first place.[10] The Commission then aims to prevent the firm from recovering any more than this acquisition/construction cost. The Commission often refers to this as the "NPV=0 rule".

[9] For example, in Appendix B of Input Methodologies (Transpower) Draft Reasons Paper, the Commission states that "…model errors cannot readily be observed or estimated. … The Commission considers it not appropriate to compensate suppliers for model errors when these cannot be quantified."

[10] See Guthrie (2009, Section 2.1.2).

28. Second, market values must be able to be obtained by discounting expected future cash flows using the expected rate of return predicted by a particular form of domestic CAPM, the so-called "simplified Brennan-Lally" modification of the standard CAPM.

29. Each of these pillars depends on a set of (often quite unrealistic) assumptions. Value maximization requires that firms are sufficiently small that their individual actions have no effect on the prices of financial securities throughout the economy, and that all risks can be hedged (that is, insured against) by trading in financial securities.[11] CAPM-style models require another set of assumptions, including that investors have a particular way of ranking competing alternatives, that they can borrow or lend unlimited amounts at the risk-free interest rate, that asset markets are frictionless and information is costless, that there are no restrictions on short-selling, and so on.[12]

30. There is now an extensive academic literature that demonstrates the poor empirical performance of the classical form of the CAPM even in circumstances that appear to fit its underlying assumptions.[13] I am not aware of any empirical testing of the particular form of the CAPM used by the Commission, certainly not to the same standard as tests of the classical form's empirical performance. The Commission seems to be using a largely untested CAPM. We have little idea of how well, or how poorly, the model performs empirically for NZ firms. This lack of knowledge regarding performance is a very real source of model risk.

31. Making matters worse, Transpower's circumstances are not a good fit for the assumptions underlying the Commission's theoretical framework, and one of the main causes is the combination of the size of Transpower and the Commission's use of a domestic CAPM.

32. The value-maximization result is fundamental to the Commission's entire approach, and a key assumption required for that result to hold is that the firm in question is a price-taker. That is, the firm is assumed to be able to issue securities and undertake investment projects without affecting the prices of, and expected rates of return on, other securities. The scale of Transpower's investment programme is so large that it is not credible to assume that, in the NZ market represented by the Commission's domestic CAPM, Transpower would be a price taker. For example, if a NZ firm decided to undertake an investment programme of comparable scale and finance it solely from NZ capital markets, the prices of existing corporate debt would be likely to fall as the market was flooded with newly-issued bonds. Likewise, the prices of construction-firm shares would be likely to rise substantially in anticipation of the greater future profitability that they would experience. Shareholders in the investing firm would not necessarily agree on whether this investment programme was desirable: shareholders with a separate shareholding in construction firms would be more likely to support the investment programme due to its positive impact on the construction firms in their portfolio, whereas shareholders with large bond portfolios would be more likely to oppose it due to its negative impact on the other bonds in their portfolio. Without unanimous shareholder agreement that the firm should maximize its market

[11] See Arnold and Shockley (2002) and Guthrie (2009, Section 2.1.1).
[12] See Copeland and Weston (1988, p 194).
[13] See, for example, Fama and French (2004).

value, there is no theoretical justification for evaluating projects by comparing their expected rate of return with the cost of capital derived from a domestic CAPM.

33. The only way to recover shareholder unanimity, and to recover any justification for using a CAPM-style model, is to assume that the firm raises capital in international capital markets, since it is much more reasonable to assume that a firm of Transpower's scale is a price-taker in global capital markets than to assume that it is a price taker in the NZ market. Returning to the example of a NZ firm undertaking a large investment programme, but this time financing it offshore, the world prices of existing corporate debt and shares in construction firms will be unchanged by the firm's actions: it is a price-taker in global capital markets. As a result, regardless of the composition of their portfolios, the firm's shareholders (who are now internationally diversified) will agree that the firm should undertake the investment if and only if doing so would increase its market value. In this case, therefore, it is appropriate to evaluate the firm's investment programme by comparing the expected rate of return with the cost of capital derived from a CAPM-style model, but it must be a CAPM for global markets, not for a closed domestic market. That is, for a firm of Transpower's scale, the entire cost of capital approach to project evaluation is justified only if an international form of the CAPM is used.

34. The scale of Transpower's investment programme poses another challenge to the assumptions underlying the Commission's approach. The CAPM implies that the only type of risk that affects investors' required rate of return is that component of risk that is correlated with the market as a whole; the component of risk that is uncorrelated with the market as a whole does not affect the required rate of return because investors are assumed to be able to diversify that component away. This is one of the central insights of the CAPM. However, if a firm's securities make up a sufficiently large proportion of a market then the component of the securities' returns that is not correlated with the market will be too large to be diversified away, in which case both systematic and unsystematic risk will affect required rates of return.

35. If Transpower is assumed to raise capital only domestically, which is an implicit assumption in the Commission's choice of a domestic CAPM, then its scale is such that it may be unreasonable to assume that its unsystematic risk can be diversified away by investors. The market is simply not large enough for full diversification to be achievable. Investors will therefore demand a premium for bearing this unsystematic risk, so that the Commission's domestic CAPM is inappropriate. If we recognise that a firm the size of Transpower raises capital in global markets then we can exploit the fact that the owners of its securities will be able to diversify its unsystematic risk away. However, once more this requires the use of an international CAPM, not the Commission's chosen domestic CAPM.

36. Many of these problems arise because the Commission is treating Transpower in much the same way that it treats a relatively small electricity lines business: the Commission sets the two firms' estimated leverage both equal to 40%, when Transpower's actual leverage is much higher; the two firms have estimated costs of capital that are calculated using a domestic CAPM, yet only the small lines business is a price-taker in the NZ capital market and has shareholders that

are able to diversify away the unsystematic risk associated with owning the firms' shares. The Commission has adopted an overly simple theoretical framework and is applying it to all firms, regardless of scale.

37. To summarize the discussion above, the classical CAPM performs very poorly empirically, even when it is applied to securities for which we might expect its performance to be relatively good. Moreover, the empirical performance of the particular form of the CAPM adopted by the Commission is largely unknown. Finally, the situation to which the Commission is applying the CAPM is incompatible with the underlying assumptions needed to support the theory. There is no reason to believe that the Commission's theoretical formulae will do a good job, and plenty of reasons to believe they will do a poor one. In short, all the ingredients are present for model error to be very substantial.

38. Given this situation, I believe that there are two paths that the Commission can follow. It can either modify its theoretical framework to one that is consistent with the economic realities facing Transpower, or it can continue to use its domestic CAPM.

    - If the Commission adopts a better theoretical framework (for example, an international CAPM would seem to be more appropriate) then I would expect model error to be reduced. However, model error would not be eliminated, since moving from a domestic CAPM to an international one eliminates just one of the many limitations of theoretical models of firms' costs of capital. Moreover, the new framework would probably be more complex, the underlying parameters more difficult to estimate, and therefore the new framework would lead to a relatively high statistical error.
    - If the Commission retains its domestic CAPM then it needs to recognise that the model error is substantial.

39. It is not clear ex ante which of these two approaches would be superior. However, either approach would be better than what the Commission is proposing to do, which is to retain its domestic CAPM and make absolutely no allowance for model error. In short, the Commission wants to have its cake (the simplicity and relatively low statistical error of its current domestic CAPM) and eat it too (the relatively low model error of a more complex theoretical framework). The Commission can have one or the other, but it cannot have both. Its current approach is incompatible with the Commission's stated acceptance of the asymmetric social costs of measurement error: by ignoring model error, the Commission is underestimating the measurement error in its cost of capital estimate, and therefore underestimating the size of the adjustment needed to minimize the social costs of under-investment.

40. I accept that the Commission is likely to continue to use its domestic form of the CAPM. This leaves the issue of choosing a value for the size of model error that is appropriate for this approach. As I have explained above, model error cannot be quantified with the same level of rigour as the adjustments for statistical error and intra-cycle variation. However, it is possible to get some understanding of what a sensible adjustment might entail. For example, if model error is of the same magnitude as the combination of statistical error and intra-cycle variation

(which we can quantify), then it is straightforward to calculate the size of the measurement-error adjustment. Since

$$\text{measurement error} = \text{statistical error} + \text{intra-cycle variation} + \text{model error},$$

it follows that the variance of measurement error equals the sum of (1) the variance of the combination of statistical error and intra-cycle variation and (2) the variance of model error.[14] If these two variances are equal—that is, model error is of the same magnitude as the combination of statistical error and intra-cycle variation—then the variance of measurement error equals two times the variance of the combination of statistical error and intra-cycle variation. Equivalently, the standard deviation of measurement error equals 1.4 (the square root of two) times the standard deviation of the combination of statistical error and intra-cycle variation. I have calculated above that the appropriate adjustment just for statistical error and intra-cycle variation is an increment of 0.9–1.1% using the 75th percentile, and 1.7–2.1% using the 90th percentile. It follows that if model error is of the same magnitude as the combination of statistical error and intra-cycle variation, then the corresponding increments are 1.25–1.55% and 2.40–2.95%.

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[14] This assumes that these two components of measurement error are uncorrelated, which is a reasonable assumption to make in this case.

Appendix: Curriculum Vitae

Graeme Guthrie

Curriculum Vitae

Updated: November 25, 2010

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Education

1993–1994 Master of Commerce (First Class Honours) in Economics, University of Canterbury.

1989–1992 Doctor of Philosophy in Mathematics, University of Canterbury.

1986–1988 Bachelor of Science (First Class Honours) in Mathematics, University of Canterbury.

Employment

2006–Present Professor, School of Economics & Finance, Victoria University of Wellington.

2005 Associate Professor, School of Economics & Finance, Victoria University of Wellington.

1999–2004 Senior Lecturer, School of Economics & Finance, Victoria University of Wellington.

1995–1998 Lecturer, Department of Economics, University of Canterbury.

1994 Tutor, Department of Economics, University of Canterbury.

1989–1992 Tutor, Department of Mathematics & Statistics, University of Canterbury.

Research Interests

Applications of real options analysis. Corporate finance, including capital budgeting, hedging behaviour. Financial economics. Industrial organization and regulation. Urban economics and real estate markets.

Teaching Experience

Corporate finance; derivative pricing; financial economics. Microeconomics. Macroeconomic theory.

RESEARCH

Book

Real Options in Theory and Practice, Oxford University Press, New York (432 pp., July, 2009). ISBN: 9780195380637

Papers in refereed journals

"A note on operating leverage and expected rates of return". *Finance Research Letters* (forthcoming).

"Learning options and binomial trees". *Wilmott Journal: The International Journal of Innovative Quantitative Finance* (forthcoming).

"Holding onto your horses: Conflicts of interest in asset management" (with Glenn Boyle and Luke Gorton). *Journal of Law and Economics* (forthcoming).

"House prices, development costs, and the value of waiting". *Journal of Urban Economics* 68, 56–71 (2010).

"Estimating unobservable valuation parameters for illiquid assets" (with Glenn Boyle and Neil Quigley). *Accounting and Finance* 49(3), 465–479 (2009).

"Carbon subsidies, taxes, and optimal forest management" (with Dinesh Kumareswaran). *Environmental and Resource Economics* 43(2), 275–293 (2009).

"How options provided by storage affect electricity prices" (with Lew Evans). *Southern Economic Journal* 75(3), 681–702 (2009).

"Assessing the integration of electricity markets using principal component analysis: Network and market structure effects" (with Lew Evans and Steen Videbeck). *Contemporary Economic Policy* 26(1), 145–161 (2008).

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"Competing payment schemes" (with Julian Wright). *Journal of Industrial Economics* 55(1), 33–67 (2007).

"Missed opportunities: Optimal investment timing when information is costly." *Journal of Financial and Quantitative Analysis* 42(2), 467–488 (2007).

"Regulating infrastructure: The impact on risk and investment." *Journal of Economic Literature* 44, 921–968 (2006).

"Pricing access: Forward versus backward looking cost rules" (with John Small and Julian Wright). *European Economic Review* 50(7), 1767–1789 (2006).

"A dynamic theory of cooperatives: The link between efficiency and valuation" (with Lew Evans). *Journal of Institutional and Theoretical Economics* 162(2), 364–383 (2006).

"Incentive regulation of prices when costs are sunk" (with Lew Evans). *Journal of Regulatory Economics* 29(3), 239–264 (2006).

"Hedging the value of waiting" (with Glenn Boyle). *Journal of Banking and Finance* 30(4), 1245–1267 (2006).

"Payback without apology" (with Glenn Boyle). *Accounting and Finance* 46(1), 1–10 (2006).

"Reply to the comments of Duckworth and Lewis" (with Michael Carter). *Journal of the Operational Research Society* 56, 1337–1341 (2005).

"Human capital and popular investment advice" (with Glenn Boyle). *Review of Finance* 9(2), 139–164 (2005).

"Risk, price regulation, and irreversible investment" (with Lew Evans). *International Journal of Industrial Organization* 23, 109–128 (2005).

"Cricket interruptus: Fairness and incentive in limited overs cricket matches" (with Michael Carter). *Journal of the Operational Research Society* 55(8), 822–829 (2004).

"The optimal design of interest rate target changes" (with Julian Wright). *Journal of Money, Credit and Banking* 36(1), 115–138 (2004).

"Investment, uncertainty, and liquidity" (with Glenn Boyle). *Journal of Finance* 58(5), 2143–2166 (2003).

"Cash flow immediacy and the value of investment timing" (with Glenn Boyle). *Journal of Financial Research* 26(4), 553–570 (2003).

"Open mouth operations" (with Julian Wright). *Journal of Monetary Economics* 46(2), 489–516 (2000).

"Testing the expectations theory of the term structure for New Zealand" (with Julian Wright and Jun Yu). *New Zealand Economic Papers* 33(1), 93–114 (1999).

"User charges for internet: The New Zealand experience" (with Michael Carter). *Telecommunications Systems* 6, 301–313 (1996).

"Recursion operators and nonlocal symmetries." *Proceedings of the Royal Society of London, Series A* 446, 107–114 (1994).

"More nonlocal symmetries of the KdV equation." *Journal of Physics A: Mathematical and General* 26, L905–L908 (1993).

"Nonlocal symmetries of the KdV equation" (with Mark Hickman). *Journal of Mathematical Physics* 344, 193–205 (1993).

Papers in refereed conference proceedings

"Financing constraints and investment timing" (with Glenn Boyle). *Proceedings of the 6th New Zealand Finance Colloquium*, Auckland (2002).

"Pricing internet: the New Zealand experience" (with Michael Carter). *Proceedings of the 3rd International Conference of Telecommunications Systems*, 153–161 (1995).

Papers under review

"Evaluating real estate development using real options analysis".

"Commodity prices and the option value of storage" (with Lew Evans).

"An intertemporal model of electricity markets with an application to climate change" (with Lew Evans and Andrea Lu).

Commissioned reports

"Measurement error and regulated firms' allowed rates of return" (August 2010).
Available at http://www.comcom.govt.nz

"Comments on the Commerce Commission's 'Input Methodologies' Draft Reasons Papers" (August 2010).
Available at http://www.comcom.govt.nz

"Further notes on incorporating real options in regulated prices" (December 2009).
Available at http://www.comcom.govt.nz/IndustryRegulation/Part4/DecisionsList.aspx

"Incorporating real options in regulated prices" (August 2009).
Available at http://www.comcom.govt.nz/IndustryRegulation/Part4/DecisionsList.aspx

"Comments on Castalia's 'Discount Rate for the Grid Investment Test"' (November 2006).
Available at http://www.electricitycommission.govt.nz/pdfs/opdev/transmis/Feb07-decision

"Estimating the WACC in a Regulatory Setting: An assessment of Dr Martin Lally's paper 'The Weighted Average Cost of Capital for Electricity Lines Businesses' of 8 September 2005" (March 2006, with Glenn Boyle and Lew Evans).
Available at http://www.iscr.org.nz

"Real options and transmission investment: the New Zealand Grid Investment Test" (February 2006, with Glenn Boyle and Richard Meade).
Available at http://www.iscr.org.nz

"The TSO and the cost of capital" (August 2004, with Glenn Boyle and Neil Quigley).
Available at http://www.comcom.govt.nz/IndustryRegulation/Telecommunications

"Comments on the Commerce Commission's paper 'TSO: Weighted average cost of capital" (May 2003, with Neil Quigley).

Available at http://www.comcom.govt.nz/IndustryRegulation/Telecommunications

"TSLRIC and the cost of capital: Further comments" (April 2003, with Neil Quigley).

Available at http://www.comcom.govt.nz/IndustryRegulation/Telecommunications

"A conservative estimate of the required increment to the WACC for the TSO" (September 2002, with Neil Quigley).

Available at http://www.comcom.govt.nz/IndustryRegulation/Telecommunications

"Can ex post rates of return detect monopoly profits?" (July 2002, with Glenn Boyle).

Available at http://www.iscr.org.nz

Miscellaneous

"Price regulation and investment: a two-way street." *ISCR Competition and Regulation Times* 19, 4–5 (2006).

"Corporate investment: Is the long-term view always best?" (with Glenn Boyle). *ISCR Competition and Regulation Times* 17, 11–12 (2005).

"Build it and they may leave: asset-stranding risk and regulation" (with Steen Videbeck). *ISCR Competition and Regulation Times* (August 2003).

"Capping network profits in a world of bad news" (with Steen Videbeck). *ISCR Competition and Regulation Times* (November 2002).

"The marginal cost of electricity: what's water worth?" (with Steen Videbeck). *ISCR Competition and Regulation Times* (July 2002).

"One filming to bind them" (with Steen Videbeck). *ISCR Competition and Regulation Times* (April 2002).

"Unbundling the debate over bundling in the dairy industry" (with Lew Evans). *ISCR Competition and Regulation Times* (April 2002).

"Milking the system for fair shares" (with Lew Evans). *New Zealand Herald* (March 15, 2002).

"Venture options: Unlocking the value of information" (with Roger Bowden). *ASX Perspective* 47–52 (2000, 1st quarter).

TEACHING

Advanced Undergraduate

2006–2010 Financial Economics

1999–2003 Corporate Finance, including capital budgeting, real options, agency theory, and signalling theory

1996–1998 Financial Economics, developing and testing a wide range of asset pricing models, starting from first principles

1995 Macroeconomic Theory, including rational expectations, asset pricing models

Graduate

2009–2010 Corporate Finance

2005–2010 Real Options

2000–2006 Derivative Pricing, using continuous time models

1995–2004 Microeconomic Theory, including mathematical economics, decision-making under uncertainty, information economics, financial intermediation, market microstructure

1995 Macroeconomic Theory, mainly applications of optimal control theory.

Post-experience

2010 Real Options

2000–2001, 2004, 2006–2008 Derivative Pricing, using discrete time models (Master of Applied Finance)

1999–2003 Corporate Finance, including capital budgeting, real options, agency theory, and signalling theory (Master of Business Administration; Master of Applied Finance)

PROFESSIONAL ACTIVITIES

Editorial Board

2009–2011 *New Zealand Economic Papers*

Refereeing

2010 *Canadian Journal of Economics. Chilean Government Commission for Scientific and Technological Development. International Journal of Industrial Organization. Journal of Real Estate Finance and Economics. Pacific Accounting Review (2). RAND Journal of Economics.*

2009 *International Journal of Central Banking. Journal of Financial Research (2). Marsden Fund. New Zealand Economic Papers. Quarterly Journal of Economics. Quarterly Review of Economics and Finance. Social Sciences and Humanities Research Council of Canada.*

2008 *Economics Letters. International Journal of Industrial Organization. Journal of Economic Surveys. Journal of Money, Credit and Banking. RAND Journal of Economics. Quantitative Finance.*

2007 *Journal of Banking and Finance. Journal of Macroeconomics. Journal of Money, Credit and Banking. New Zealand Economic Papers. Oxford Bulletin of Economics and Statistics. Social Sciences and Humanities Research Council of Canada.*

2006 *Journal of Agricultural and Resource Economics. Journal of Banking and Finance.*

2005 *International Journal of Industrial Organization. Journal of Banking and Finance (2). Journal of Futures Markets. Journal of Money, Credit and Banking. Journal of Regulatory Economics. Pacific Accounting Review.*

–2004 *Agenda. Economic Journal. Journal of Finance. Journal of Mathematical Physics. Journal of Money, Credit and Banking (3). New Zealand Economic Papers. Studies in Economics and Finance.*

Doctoral Thesis Examiner

2006 Victoria University of Wellington

2006 University of Canterbury

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