Further Notes on Incorporating Real Options in Regulated Prices

Submission to the New Zealand Commerce Commission on behalf of Telecom New Zealand Ltd

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1 Introduction

1. In this submission I wish to respond to various matters raised at the Commerce Commission's Cost of Capital Workshop on 12–13 November, 2009.

2. My discussion focuses on three separate issues:

   2.1 How should we interpret the evidence that firms typically choose investment hurdle rates in excess of their estimated cost of capital?

   2.2 How does the presence of real options affect the market values and rates of return of unregulated firms, and how can these outcomes be replicated for regulated firms?

   2.3 How can the Commission implement the "multiplier approach" to incorporating real options in regulated prices, which I described in my earlier submission to the Commission (Guthrie, 2009a)?

2 Explanation for high observed hurdle rates

3. There was some discussion at the Cost of Capital Workshop concerning anecdotal and empirical evidence that firms typically set investment hurdle rates at levels considerably above their estimated cost of capital. That is, even unregulated firms without market power require an expected rate of return substantially in excess of their cost of capital before they are willing to invest in a project. This suggests that regulated firms should also be allowed an expected rate of return that is greater than their estimated cost of capital.

4. However, Commissioner Duignan commented that (Transcript, Day 1, pp. 73–74)

   > *"You set a hurdle rate, the term 'hurdle' is implying that you are looking for a, or expecting a Project Manager who is a promoter of a project and who is going to somebody who authorises him to let him go ahead with what he wants to do. It may be the lazy way of doing it and it's not what corporate finance says, corporate finance says you should put in sensitivities etc, but practically everybody on the ground sets a rate above what they expect would be good enough because they are allowing for the optimism. I really have to stress that that is the real world of corporate finance in companies, and that references to hurdle rates really don't get past that problem that if you interviewed executives they would almost certainly, the majority of them would sort of describe what I just described."*

5. I agree that anticipating project-manager optimism is a contributing factor to firms setting hurdle rates in excess of their estimated costs of capital. However, detailed econometric studies show that project-manager optimism cannot be the only explanation for hurdle rates exceeding estimated costs of capital.

6. For example, a recent study by Chirinko and Schaller (2009) uses data on investment expenditure and *actual* project outcomes—that is, actual sales and operating costs, etc., not expected sales and operating costs forecast by project managers—and finds hurdle rates well in excess of CAPM-based costs of capital.

   6.1 Because this study uses actual project outcomes, the premia that it detects cannot be explained as responses to project-manager optimism: project managers can inflate a project's forecast cash flows in their project evaluation, but they cannot inflate its actual cash flows.

   6.2 If the only explanation for hurdle rates being higher than the estimated cost of capital was that this is a response to project-manager optimism, then firms would invest to the point that the marginal unit of installed capital earns—on average—the firm's cost of capital and nothing more.[1] However, Chirinko and Schaller (2009) show that the marginal unit of installed capital earns considerably more than the cost of capital on average.

   6.3 The premia they find are economically significant. For example, they estimate that firms with limited resale markets set hurdle rates 5.1% higher than their cost of capital; firms with low depreciation rates set them 2.2% above their cost of capital; those with high demand uncertainty set them 7.3% above their cost of capital (Chirinko and Schaller, 2009, p. 391).

   6.4 Finally, this study uses a sample of 127,863 observations on 16,140 U.S. publicly traded firms during the period 1980–2001, so that the results are likely to be representative of the universe of U.S. publicly traded firms, regulated and unregulated, with and without market power.

7. I am not suggesting that project-manager optimism is not a concern when setting hurdle rates. Rather, I am highlighting empirical evidence that says it cannot be the only concern. Moreover, this empirical evidence identifies economically-significant premia that cannot be attributed to project-manager optimism.

3 Real options and the allocation of value

8. The discussion of real options at the Cost of Capital Workshop raised a number of issues, which I address in this section. Much of the discussion centered around the source of the value associated with growth options, how this value is allocated to investors in unregulated firms, and how this allocation could be replicated for regulated firms.

9. I begin by working through the details of a numerical example that shows what happens when an unregulated firm adopts a hurdle rate greater than its cost of capital.[2]

[1] This average is based on actual outcomes; it is not the "average" outcome as chosen by project managers.

[2] This is in response to Commissioner Duignan's request for some worked examples to clarify various issues surrounding the multiplier approach (Transcript, Day 1, p. 69).

9.1 I show how the firm's market value can be decomposed into the values of its cash stock, its assets-in-place, and its growth option.

9.2 I also show how this decomposition changes over time as the investment event approaches, as well as what happens when investment occurs.

9.3 I address one particular suggestion made at the Cost of Capital Workshop, which is that the returns from exercising firms' real options are already included in the historical rates of return on the market that are used to estimate the market risk premium, so that there is no need to provide additional compensation for real options. I explain why market returns do not include an "option premium" and why separate consideration of real options is required.

9.4 There was a lengthy discussion at the Cost of Capital Workshop concerning the way in which firms are compensated for the loss of option value resulting from acts of investment. There was some suggestion that if growth options increase in value over time then no explicit compensation for real options is required. I explain why this conclusion is incorrect.

10. The second part of this section shows how the same pattern of cash flows can be achieved for a regulated firm using the "real option multiplier" approach in Guthrie (2009a).

3.1 Real options and the unregulated firm

11. I begin by introducing a numerical example involving an unregulated firm with the option to invest.

12. Consider an unregulated firm that currently holds \$150 in cash and owns the option to invest in a project that requires capital expenditure of \$100 and will generate a perpetual cash flow of \$$x$ per annum, beginning one year after investment occurs. Suppose that all cash flows have zero systematic risk and that the risk-free interest rate is 8% per annum. That is, the firm's WACC is 8%. Suppose also that the firm sets a hurdle rate of 10% per annum. Currently $x = 9$ but if the firm delays investment for two years then it will be able to invest and receive $x = 10$. To make the analysis as simple as possible, the firm does not pay any dividends and there are no taxes. The discussion below is summarized in Table 1.

12.1 The firm will not invest immediately, because the project's IRR is currently just 9%, less than its hurdle rate. Instead, the firm will invest two years from now, when it will pay \$100 and receive a completed project worth $10/0.08 = 125$ dollars.

12.2 Consider the situation two years from now, immediately *after* investment. The firm will hold \$74.96 of cash, comprising its initial balance of \$150, plus interest of \$12.00 in the first year and \$12.96 in the second year, minus the \$100 used to build the project. The firm will also own a completed project worth \$125, for a total future value of \$199.96.

Table 1: Effect of investment on growth options and assets-in-place

Year	Net cash flow			Market value			
	Interest	Operations	Capex	Cash	Growth option	Asset	Firm
0				150.00	21.43	0.00	171.43
1	12.00	0.00	0.00	162.00	23.15	0.00	185.15
2 (before invt)	12.96	0.00		174.96	25.00	0.00	199.96
2 (after invt)			100.00	74.96	0.00	125.00	199.96
3	6.00	10.00	0.00	90.96	0.00	125.00	215.96
4	7.28	10.00	0.00	108.23	0.00	125.00	233.23
5	8.66	10.00	0.00	126.89	0.00	125.00	251.89
6	10.15	10.00	0.00	147.04	0.00	125.00	272.04
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

12.3 Next, consider the situation two years from now, immediately *before* investment. The firm will hold \$174.96 of cash (since it has not yet paid to build the project) and a growth option worth \$25 (the difference between the value of the completed project and the required capital expenditure). The firm is again worth \$199.96.

12.4 Now move backwards in time one year, to consider the situation one year from now. The firm's cash stock will equal \$162 (the initial stock of \$150 plus \$12 in interest). The market will anticipate that after one further year the firm will be worth \$199.96, so that the firm is worth

$$\frac{199.96}{1 + 0.08} = 185.15$$

dollars. That is, its cash stock of \$162 is worth \$162 and its growth option is worth \$23.15.

12.5 What does this mean for the value of the firm today? The market value of the firm one year from now will be \$185.15, implying a market value today of

$$\frac{185.15}{1 + 0.08} = 171.43$$

dollars. That is, its cash stock of \$150 is worth \$150 and its growth option is worth \$21.43.

12.6 Table 1 also shows how the firm's value evolves after it invests (that is, from date 3 onwards).

13. During the Cost of Capital Workshop, it was suggested that the returns from exercising firms' real options are already included in the historical rates of return on the market that are used to estimate the market risk premium and that this means there is no need to provide additional compensation for real options. For example, Commissioner Duignan asked (Transcript, Day 1, pp. 64–65)

> *"...if we think of what we're trying to do is get a WACC estimate that is the historical mean internal rate of return of the entire market, if that was what we were doing, then*

for the market NPV equals zero would automatically follow, it appears to me; and so at some point perhaps when we come to the real options I'm puzzled by the proposition that the real options are sort of outside the record of what returns have been earned in the global, or the overall equity market."

He subsequently raised the possibility that (Transcript, Day 1, p. 67)

"the WACC would take into account options and if we applied it we would be applying a WACC that properly accounted for options on average."

14. However, the historical rates of return used to estimate the WACC will not include a "real option premium".

14.1 In efficient financial markets shareholders will not earn "excess" returns on average, no matter what investment policies firms follow: prices will be bid up (or down) in order to eliminate the prospect of such returns occurring.

14.2 This argument applies to firms' growth options, just as it applies to other assets. The current market value of a firm's growth options is determined by the market in such a way that excess returns are not earned on average. This means that the option premium is built into the market value of the owning firm, not into the rate of return that shareholders receive from trading in the firm's shares. In particular, even if a firm chooses a hurdle rate in excess of its cost of capital, its shareholders will *not* earn an excess rate of return on their investment in the firm's shares on average.

14.3 Consider the example above. Investors in this firm earn a rate of return over the first year equal to

$$\frac{185.15 - 171.43}{171.43} = 0.08$$

and over the second year they earn a rate of return equal to

$$\frac{199.96 - 185.15}{185.15} = 0.08.$$

The market values reported in Table 1 for year 3 onwards also imply that investors earn an 8% rate of return in all future years. That is, even though the firm chooses a hurdle rate of 10%, the market rate of return from investing in the firm's shares is only 8%.

14.4 As this example demonstrates, investor rates of return for individual firms do not contain an option premium when those rates of return are calculated using the firm's market value. The same is true for portfolios of firms. In particular, the historical rates of return used to estimate the market risk premium do not include a real option premium. Thus, the market risk premium used in the CAPM formula does not compensate shareholders for the fall in growth options' value caused by investment.

15. Now I turn to the issue of how investment affects the market value of an unregulated firm. The market value of such a firm equals the sum of its cash holdings, the market

value of its assets-in-place, and the market value of its growth options. The individual components, and the sum, change over time as market conditions change.

16. While a firm is waiting to invest, its growth option may fluctuate in value, falling in value whenever the prospects for investment worsen and increasing in value when they improve. The value of the growth option today will be set by the market at such a level that the expected capital gain does not allow excess returns on average.[3]

17. Each time a firm invests, the sum of the changes in the market values of assets-in-place and growth options equals the amount of capital expenditure. Thus, if investment reduces the value of the firm's growth options, then its assets-in-place must increase in value by the sum of the amount of capital expenditure and the fall in value of the growth options.

18. Growth options do not generate cash flow until they are exercised. Consequently, if they have a positive market value today then it must be the case that the market expects them to generate a positive net cash flow in the future. For example, bare land in the inner city has positive value because investors anticipate that at some future date its owner will be able to construct a building on the land and sell it for an amount in excess of the construction expenditure.

19. This behaviour can be seen in the example above.

    19.1 Table 1 shows how the value of the firm and its constituent values of cash, growth options, and assets-in-place evolve over time. Initially the growth option increases in value, even though it is generating no cash flow for the firm. When the firm invests, its cash stock falls by the $100 of capital expenditure, the growth option falls in value by $25, and the assets-in-place increase in value by $125. In particular, the value of the firm's assets-in-place increases by more than the amount of capital expenditure.

    19.2 The firm spends $100 of capital expenditure, but subsequently earns a net cash flow of $10 from the project each year. We can think of this either as earning a rate of return of 10% on its capital expenditure (that is, its WACC of 8% and a "real option premium" of 2%) or earning the firm's WACC of 8% on the total cost of $100 + 25 = 125$ dollars, where $100 is the amount of capital expenditure and $25 is the reduction in value of the firm's growth option at the time of investment.

20. When a firm is able to make a sequence of investments, we might expect to see a "sawtooth" pattern in the value of its growth options. Initially the value of growth options is relatively low. As the investment environment improves, they grow in value.[4] Eventually, the firm will make its first investment, which leads to a jump upwards in the value of its assets-in-place and a jump downwards in the value of its growth options. As time

[3]Note that there is no cash flow component to the return prior to investment occurring.

[4]Indeed, the market value of the firm's growth options will be set in such a way that—on average—they increase in value at a risk-adjusted rate of return, such as the one implied by the CAPM.

passes, and the investment environment improves, the growth options grow in value once more. Eventually, the firm will make its second investment, which leads to another jump upwards in the value of its assets-in-place and a jump downwards in the value of its growth options.

21. Appendix A.1 contains an extension of the numerical example introduced above. In the extended example, the firm invests on two separate occasions, which allows me to demonstrate the saw-tooth pattern in growth-option value.

22. During the Cost of Capital Workshop, Commissioner Duignan commented that (Transcript, Day 1, p. 68)

> *"Now if we're looking at longish periods for historical rates of return, then you are either saying again that the options are the same amount of options at the beginning as at the end, and so there's no need for a return on them because you're actually building back up your stock of options as you're using them up, which if it's true says that the option analysis is interesting but for the market as a whole it's irrelevant because the level is just staying constant; it's certainly important for individual firms but for the taking - that's the whole point about diversification, if that was what you were saying."*

One interpretation of this comment (I am not sure if it is the one intended by Commissioner Duignan) is that firms do not need to earn a return on the loss of growth-option value due to individual acts of investment if, in the long run, the value of growth options is reasonably constant.

22.1 However, consider the saw-tooth pattern of option values. Recall that market efficiency requires that on average growth options increase in value at a risk-adjusted discount rate (for example the rate implied by the CAPM) during periods when the firm does not invest. The only way that the value of growth options can be approximately constant in the long-run is if they tend to fall in value when the firm invests, so that the periodic jumps downwards offset the gradual increases between jumps.

22.2 Any reduction in value of growth options at the time of investment must be offset by an increase in the value of the firm's assets-in-place over and above the amount of capital expenditure, as in the example in Table 1.

22.3 In other words, even if the value of a firm's growth options is approximately constant in the long run, its shareholders still benefit from those growth options via assets-in-place increasing in value by more than the amount of capital expenditure when the firm invests.

3.2 Real options and the regulated firm

23. Some of the discussion at the Cost of Capital Workshop suggests that the explanation of the multiplier approach in Guthrie (2009a) was unclear. In particular, there seems to be

some confusion surrounding how and when real options are incorporated in a regulated firm's rate base and how this affects the firm's cash flows.

24. The multiplier approach works by augmenting each item of capital expenditure by a fixed percentage at the time it is added to the rate base. This is the *only* change to current practice.

25. The capital expenditure is augmented by an amount equal to the reduction in market value of the firm's growth options that occurred as a consequence of the investment. This ensures that the firm's owners receive compensation *only* for the firm's capital expenditure and the loss in value of growth options associated with that capital expenditure.[5]

26. There was a lengthy discussion at the Cost of Capital Workshop about how the multiplier approach's treatment of real options compared to what we see in an unregulated market. For example, Commissioner Begg asked (Transcript, Day 1, p. 65)[6]

> *"...in the case of a regulated business when you destroy these flexibility options, the regulatory asset base doesn't change. I just wonder how that sort of fits together with the model in an unregulated market versus a regulated market..."*

27. If the multiplier approach is followed then—at each point in time—the regulated firm's rate base will equal the market value of the unregulated firm's assets-in-place. The two firms will have identical net cash flows, and they will therefore have the same market value. That is, the multiplier approach mimics what we would see in an unregulated market.

28. The following continuation of the earlier example demonstrates how the multiplier approach would work in practice. It features the same firm as in the previous example. However, whereas the firm was unregulated in that example, in this one it is regulated according to the multiplier approach. The rate base is initially zero and, as soon as the firm invests, the rate base is increased by the product of its capital expenditure and the real option multiplier $M = 1.25$.[7] As in the previous example, the firm pays no dividends and there are no taxes.

    28.1 Each year the firm earns interest on its cash stock and earns a rate of return on its (augmented) rate base equal to its WACC of 8%.

    28.2 The firm's cash flows are summarized in Table 2. It incurs capital expenditure of \$100 at date 2, at which point the rate base is raised from \$0 to \$125. From date 3

[5] In particular, fluctuations in the value of the firm's growth options due to changes in market conditions have no impact on the firm's rate base, and therefore no effect on its allowed revenue.

[6] Note, however, that under the multiplier approach the rate base *would* change when flexibility options are destroyed: it would increase by the value of the destroyed options, provided their destruction is a consequence of the regulated firm's investment.

[7] Consistent with the perpetual nature of the asset, no allowance is made for depreciation. Finite asset lives could be introduced, but doing so complicates the arithmetic without providing any additional insights.

Table 2: Demonstration of the multiplier approach to regulation

Year	Net cash flow			Cash	Rate
	Interest	Operations	Capex		base
0				150.00	0.00
1	12.00	0.00	0.00	162.00	0.00
2 (before invt)	12.96	0.00		174.96	0.00
2 (after invt)			100.00	74.96	125.00
3	6.00	10.00	0.00	90.96	125.00
4	7.28	10.00	0.00	108.23	125.00
5	8.66	10.00	0.00	126.89	125.00
6	10.15	10.00	0.00	147.04	125.00
⋮	⋮	⋮	⋮	⋮	⋮

onwards, the firm's assets generate allowed net revenue of $10, representing a return of 8% on the firm's (augmented) rate base.

28.3 Note that the firm's cash flows are identical to those in the earlier example. In addition, at each point in time the regulated firm's rate base equals the market value of the unregulated firm's assets-in-place.

29. In practice, a regulated firm will make a sequence of investments, leading to the saw-tooth pattern in the value of its growth options that was described above. These grow in value—on average—during periods when the firm does not invest, and they experience sudden (typically downward) jumps in value whenever investment occurs. The firm's assets-in-place experience (upward) jumps in value whenever investment occurs. If the multiplier approach is used (and the multiplier is calculated correctly) then each time the regulated firm invests, its rate base increases by the sum of the amount of capital expenditure and the reduction in value of the firm's growth options.[8] This ensures that the firm's rate base tracks the value of the corresponding unregulated firm's assets-in-place.

30. The extended example in Appendix A.1 demonstrates the application of the multiplier approach in the presence of this saw-tooth pattern. The example shows that the regulated firm receives the same net cash flow as the unregulated one and that its rate base equals the market value of the unregulated firm's assets-in-place.

4 Estimating real option multipliers

31. At the Cost of Capital Workshop Commissioner Duignan stated that (Transcript, Day 1, p. 97)

[8]Note that the second term is the amount by which the value of the firm's growth options falls, it is not the value of the growth options before investment. That is, the multiplier approach does not involve any "double counting".

> *"... the position following the experts' report is that the Commission confronts both major obstacles of an analytical nature regarding any question of allowing for real options and also one of a pretty significant nature regarding the issue of distinguishing between options that are due to the natural monopoly characteristics and market power that goes with it versus other types of options, and so we would need, if that matter was to be explored much further, input from the industries regarding those aspects."*

The challenge facing the Commission is to estimate the effect that investment has on the value of firms' growth options in workably competitive markets.

32. If the firms being regulated were operating in workably competitive markets then there would be no need for regulation. Any method for calculating option values therefore needs to confront the fact that competition would not "work" in these particular markets. This means that there is no point in building models of particular firms that capture *all* aspects of their circumstances and then asking what competition would look like. For instance, if there are economies of scale in investment then a competitive process would tend to result in a single firm dominating the market. An option value for such a firm would be contaminated by the market power that the Commission is trying to filter out.

33. It follows that any attempt to estimate workably-competitive option values cannot be tied too closely to the particular circumstances of the firm being regulated. Some aspects of that firm's situation will need to be varied for the hypothetical workable competition to make sense.

34. In this section I briefly motivate and describe three separate approaches that the Commission might consider, each based on a well known real option model. Each model might reasonably be regarded as describing a workably competitive market. Most of the parameters needed to describe each model can be estimated to match the circumstances of the firm being regulated, but one parameter—the one determining the nature of competition—cannot be.

    - Approach #1: Competition is captured by the probability that the firm's growth option is lost due to preemption by another firm.
    - Approach #2: Competition is captured by the price elasticity of supply in the market.
    - Approach #3: Competition is captured by the number of identical firms operating in the market.

    In each case, if the relevant parameter was set to match the regulated firm's circumstances, there would be no (or little) competition and the implied option values that the Commission would calculate would include the benefits of market power. Therefore, the Commission needs to decide what "workable competition" means for the parameter in question. For example: How long can a firm wait on average in a workably competitive market before it is preempted? How many firms operate in a workably competitive market?

35. The role of the real option model is to translate the Commission's assumption about workable competition into a real option multiplier that can be used to ensure the regulated firm receives adequate compensation for the value of growth options lost when investing.

4.1 Approach #1: Mimicking the threat of preemption

36. McDonald and Siegel (1986) developed one of the earliest and simplest models of investment timing. In their model a firm holds a perpetual option to develop a project. The market value of the completed project (including the value of any embedded options, such as the option to contract or expand in the future) and the required amount of capital expenditure evolve randomly over time, and investment is irreversible. Their model is easily modified so that the development option is not perpetual. Specifically, the option can be assumed to be extinguished at some unknown future date. We can think of this as capturing the threat of preemption that might arise in a workably competitive market.

- Under perfect competition we might expect the firm to be preempted if it delayed investing—even for an instant—when the asset created by investment is worth more than the capital expenditure required. In this case, the expected time until preemption is zero.
- At the other extreme, if the firm is the only one able to invest it could delay indefinitely without any threat of preemption. In this case, the expected time until preemption is infinite.
- Workable competition will lie somewhere between these two extremes.

37. As shown in Appendix B.1, in the special case where there is no capital-expenditure risk, this leads to the option multiplier[9]

$$M = 1 + \frac{1}{\theta - 1},$$

where

$$\theta = \frac{1}{2} + \frac{\lambda - \mu}{\sigma^2} + \sqrt{\frac{2(r+\phi)}{\sigma^2} + \left(\frac{1}{2} + \frac{\lambda - \mu}{\sigma^2}\right)^2}$$

and

$$\begin{aligned} r &= \text{risk-free interest rate,} \\ \lambda &= \text{project-risk premium (that is, } RADR - r), \\ \mu &= \text{average annual growth rate in the value of the completed project,} \\ \sigma &= \text{volatility of the annual growth rate in the value of the completed project,} \\ 1/\phi &= \text{average number of years until preemption.} \end{aligned}$$

[9] The general case with stochastic capital costs is not much more complicated and leads to a similar expression for θ. It can be calculated by adding $1/\phi$ to the interest rate where it appears in the investment thresholds given in McDonald and Siegel (1986).

Table 3: Option multipliers and the threat of preemption

Preemption parameter	ϕ	Infinite	1.00	0.50	0.20	0.10	0.01	0
Average years until preemption	$1/\phi$	0	1	2	5	10	100	Infinite
Multiplier	M	1.00	1.15	1.21	1.33	1.46	1.86	2.00

38. All parameters except for ϕ can be calibrated to the firm (or industry) being regulated. Two of them (r and λ) are calculated as part of the Commission's WACC estimation procedure. The others (μ and σ) will require more work, with the approach adopted depending on the nature of the asset and the data available. For example, if historical usage data are available, then μ and σ can be estimated from the average and standard deviation of actual growth rates.[10] In some cases, it may be possible to infer values of μ and σ from comparison firms, using a "de-levering" process analogous to that used to convert equity betas into asset betas (Guthrie, 2009b, Section 14.2.3).

39. The market power enjoyed by the regulated firm means that it may have considerable ability to wait without fear of losing its growth options. Thus, the calibrated level of ϕ would be close to zero. The Commission therefore needs to choose a level of ϕ that it believes reflects what workable competition would look like in the industry under consideration. In practice, it would be more natural to choose the average length of time until preemption and then set ϕ equal to the reciprocal of this number. The Commission might consider factors such as the length of time needed to plan and implement investment projects in the industry being regulated. In those industries with long investment lead times, $1/\phi$ might reasonably take a relatively high value.

40. Dixit and Pindyck (1994) discuss the special case of no preemption risk. Their baseline example has $r = 0.04$, $\lambda = 0$, $\mu = 0$, and $\sigma = 0.2$, which implies an option multiplier of $M = 2$ (Dixit and Pindyck, 1994, p. 153).[11] Table 3 shows the effect of the average time until preemption for these parameter values. Notice that the only way that the option multiplier equals one (so that no compensation for lost growth-option value is required) is if the firm would be preempted immediately if it delayed undertaking the investment: this is perfect competition, not workable competition.

41. The principal advantages of this approach are its simplicity, its transparency, the fact that it is not tied too closely to any particular firm or industry (although the particular parameter values used would be industry-specific), and the intuitive way in which it captures the effect of workable competition on investment timing flexibility.

[10] In the general model, with stochastic capital costs, historical data on capital prices can be used in much the same way. Averages and standard deviations of actual growth rates in usage and capital prices, together with the correlation coefficient between usage growth and capital-price growth, are sufficient to estimate μ and σ.

[11] These parameter values are chosen solely to illustrate the approach. They are not necessarily representative of the firms that the Commission regulates.

4.2 Approach #2: Competitive equilibrium with lumpy investment

42. Novy-Marx (2007) derives equilibrium investment policies in a competitive industry in which investment is lumpy and intermittent. An infinite number of atomistic firms compete in a product market. At any point in time, different firms potentially have different productive capacities, and this heterogeneity leads to cross-sectional variation in the opportunity cost of investment. There are decreasing returns to scale in investment, which prevents any single firm from growing until it takes over the entire market. This assumption is not likely to match the realities of firms regulated by the Commission, but—as discussed earlier—such differences are the price we must pay for measuring option values in workably competitive markets.

43. Novy-Marx (2007) decomposes the value of the competing firms into the value of their assets-in-place and the value of their growth options. Investment does not destroy these options, it merely alters their value in a way that is broadly consistent with the saw-tooth pattern discussed above. The implied option multiplier rewards firms only for changes in option value at the time each investment occurs.

44. As shown in Appendix B.2, the option multiplier is

$$M = 1 + \frac{1}{\theta - 1},$$

where

$$\theta = \left(1 + \frac{\varepsilon_S}{\varepsilon_D}\right)\left(\frac{1}{2} + \frac{\lambda - \mu}{\sigma^2} + \sqrt{\frac{2r}{\sigma^2} + \left(\frac{1}{2} + \frac{\lambda - \mu}{\sigma^2}\right)^2}\right)$$

and

$$\begin{aligned}
r &= \text{risk-free interest rate,} \\
\lambda &= \text{demand-risk premium (that is, } RADR - r\text{),} \\
\mu &= \text{average annual growth rate in demand,} \\
\sigma &= \text{volatility of annual growth rate in demand,} \\
\varepsilon_D &= \text{price elasticity of demand,} \\
\varepsilon_S &= \text{price elasticity of supply.}
\end{aligned}$$

45. All of these parameters can be estimated for the particular industry being regulated, with the exception of ε_S.[12] r and λ will be available from the WACC calculation, while μ and σ can be estimated along the lines discussed for the first approach. Estimating ε_D, the price elasticity of demand, is a problem not unique to real options analysis, and established techniques can be applied to the problem here.

[12] The price elasticity of supply is actually endogenously determined in this model, being equal to $1/(\gamma - 1)$, where the level of γ (which must exceed 1) determines the investment returns to scale (Novy-Marx, 2007, Proposition 1). Specifically, beyond the level of the output price that triggers investment, each one percent increase in the output price is associated with an ε_S per cent increase in the capital stock.

Table 4: Option multipliers in a competitive equilibrium with lumpy investment

Price elasticity of supply	ε_S	5.00	2.00	1.00	0.50	0.25	0.10	0.00
Multiplier	M	1.13	1.27	1.43	1.60	1.75	1.88	2.00

46. I would expect regulated firms to have lower levels of ε_S than would occur in a workably competitive market. We therefore need to vary ε_S from its estimated value in order to capture the effects of workable competition.

47. Consider the baseline example from above, which has $r = 0.04$, $\lambda = 0$, $\mu = 0$, and $\sigma = 0.2$. Table 4 shows the effect of the price elasticity of supply on the real option multiplier for these parameter values, assuming that the price elasticity of demand is $\varepsilon_D = 1.5$.

48. Compared to the first approach, this one is built on a properly developed model of equilibrium in a competitive market. However, the highly technical nature of the underlying model suggests that this approach might be best used as a "common sense" check on the first approach, rather than as the sole basis for calculating real option multipliers.

4.3 Approach #3: Competitive equilibrium with incremental investment

49. Grenadier (1996) derives equilibrium investment policies in a competitive industry in which physical capital is infinitely divisible and the number of firms is finite and exogenously specified. Equilibrium investment is incremental and so probably not a good fit for the industries that the Commission regulates.

50. In the special case where the demand shock follows geometric Brownian motion and the price elasticity of demand is constant, the option multiplier is

$$M = 1 + \frac{1}{n\varepsilon_D - 1},$$

where n is the number of firms and ε_D is the price elasticity of demand.

51. Although the underlying assumptions and the implied investment behaviour are unrealistic, this approach has the advantage that it only requires estimation of the price elasticity of demand.[13] Standard techniques are available for this task.

52. The Commission will need to specify the number of firms in its hypothetical workably competitive market.

[13]Alternative specifications (for example, linear demand) are possible (Grenadier, 1996, Section 6). In many of these specifications the option multiplier will depend on more parameters than just n and ε_D. For example, demand volatility will be relevant. However, the additional parameters can be estimated in much the same way as the parameters in the first two approaches. For example, r and λ are already available from the WACC calculations, while μ and σ can be estimated from historical usage data.

Table 5: Option multipliers in a competitive equilibrium with incremental investment

Number of firms	n	1	2	5	10	100	Infinite
Multiplier	M	3.00	1.50	1.15	1.07	1.01	1.00

53. Consider the baseline example from above, which has price elasticity of demand equal to $\varepsilon_D = 1.5$. Table 5 shows the effect of the number of firms on the size of the real option multiplier.

4.4 Concluding remarks

54. In this section I have presented three separate approaches to estimating the size of the real option multiplier. Each is based on a well known model, each requires the Commission to specify a single parameter to operationalize the notion of workable competition, and in each case the remaining parameters can all be calibrated to the industry or firm being regulated.

55. I believe that the first approach could form a suitable basis for the Commission's calculation of an industry-specific real option multiplier. The underlying model is reasonably well known and well understood, and the associated concept of workable competition is easily grasped. The second approach might form a "common sense" check, but the complexity of the underlying model means that it would be a fairly opaque way of estimating the multiplier. The third approach is similarly best used as a "common sense" check: although the expression for the multiplier is straightforward, the underlying model is not and, moreover, the simplicity of the expression is very sensitive to the model's specification.

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Table 6: Effect of investment on growth options and assets-in-place when the firm invests twice

Year	Net cash flow			Market value			
	Interest	Operations	Capex	Cash	Growth option	Asset	Firm
0				150.00	39.81	0.00	189.81
1	12.00	0.00	0.00	162.00	42.99	0.00	204.99
2 (before invt)	12.96	0.00		174.96	46.43	0.00	221.39
2 (after invt)			100.00	74.96	21.43	125.00	221.39
3	6.00	10.00	0.00	90.96	23.15	125.00	239.10
4 (before invt)	7.28	10.00		108.23	25.00	125.00	258.23
4 (after invt)			100.00	8.23	0.00	250.00	258.23
5	0.66	20.00	0.00	28.89	0.00	250.00	278.89
6	2.31	20.00	0.00	51.20	0.00	250.00	301.20
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

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Appendices

A.1 An example with two projects

56. This appendix extends my numerical example to examine the situation where a firm makes a sequence of investments, generating a saw-tooth pattern in the value of growth options. The only change I make to the set-up of the earlier example is that the firm invests a second time—at year 4—on identical terms to its investment at year 2. That is, it incurs $100 of capital expenditure at year 2, initiating a perpetual cash flow of $10 per annum starting at year 3; it incurs another $100 of capital expenditure at year 4, initiating an additional perpetual cash flow of $10 per annum starting at year 5. All other aspects of the firm's situation are unchanged. Table 6 shows the sequence of cash flows and market values for the new case, using the same format as Table 1.

57. The firm's growth options are initially worth $39.81, reflecting the market value of both future investment opportunities; the firm initially has no assets-in-place. Immediately before investment at year 2, the firm's growth options are worth $46.43, reflecting the new market value of the two investment opportunities; the firm still has no assets-in-place. When the firm invests at year 2, it pays $100 from its cash stock and its growth options fall in value from $46.43 to $21.43 (a fall of $25). That is, the cost of the first

Table 7: Demonstration of the multiplier approach to regulation when the firm invests twice

Year	Net cash flow			Cash	Rate
	Interest	Operations	Capex		base
0				150.00	0.00
1	12.00	0.00	0.00	162.00	0.00
2 (before invt)	12.96	0.00		174.96	0.00
2 (after invt)			100.00	74.96	125.00
3	6.00	10.00	0.00	90.96	125.00
4 (before invt)	7.28	10.00		108.23	125.00
4 (after invt)			100.00	8.23	250.00
5	0.66	20.00	0.00	28.89	250.00
6	2.31	20.00	0.00	51.20	250.00
⋮	⋮	⋮	⋮	⋮	⋮

project to the firm is \$125. Note that the value of the firm's assets-in-place increases by exactly this amount.

58. Immediately after investment at year 2, the firm's growth options are worth \$21.43, reflecting the market value of the sole remaining investment opportunity; the firm has assets-in-place worth \$125. By year 4 (immediately before investment), the firm's growth options have increased in value to \$25 and its assets-in-place are worth \$125. When the firm invests at year 4, it pays \$100 from its cash stock and its growth options fall in value from \$25 to zero. That is, the cost of the second project to the firm is \$125. Once again, the value of the firm's assets-in-place increases by exactly this amount.

59. The same outcome can be achieved for a regulated firm using the multiplier approach: capital expenditure is augmented by a factor of $M = 1.25$ whenever it is added to the rate base. This augmentation ensures that investors are compensated for the reduction in the value of the firm's growth options that occurs each time that the firm invests. The rate base is initially zero. When the firm invests at year 2, the rate base increases by \$125 (the product of the multiplier and the capital expenditure of \$100); it increases by another \$125 when the firm invests at year 4. The firm's cash flows are summarized in Table 7.

B.1 Modifying McDonald and Siegel (1986)

60. Consider the special case where the expenditure required to build the project is constant (and equal to I). The risk-neutral process for the market value of the completed project is

$$dV_t = (\mu - \lambda)V_t dt + \sigma V_t d\xi_t.$$

The investment option dies with probability $\phi\, dt$ during any interval of time of length dt. The risk-free interest rate equals r. Denote the market value of the project rights by $F(V)$.

61. The (risk-adjusted) expected payoff from waiting dt years and then reconsidering the situation is

$$(1 - \phi\, dt)(F + E^*[dF]) + \phi\, dt \cdot 0 = F + E^*[dF] - \phi F\, dt.$$

This expected payoff equals $F + rF\, dt$ when financial markets are in equilibrium, so that F satisfies

$$0 = \frac{E^*[dF]}{dt} - (r+\phi)F = (\mu - \lambda)VF'(V) + \frac{1}{2}\sigma^2 V^2 F''(V) - (r+\phi)F.$$

62. If the firm invests as soon as $V \geq \hat{V}$ then the project rights are worth

$$F(V) = (\hat{V} - I)\left(\frac{V}{\hat{V}}\right)^{\theta},$$

where

$$\theta = \frac{1}{2} + \frac{\lambda - \mu}{\sigma^2} + \sqrt{\frac{2(r+\phi)}{\sigma^2} + \left(\frac{1}{2} + \frac{\lambda-\mu}{\sigma^2}\right)^2}.$$

63. The optimal investment threshold, which maximizes $F(V)$, is

$$\hat{V} = \frac{\theta}{\theta - 1} I = \left(1 + \frac{1}{\theta - 1}\right) I.$$

That is, the firm will invest only when the market value of the completed project is greater than or equal to MI, where

$$M = 1 + \frac{1}{\theta - 1}.$$

This is the real option multiplier implied by this model.

B.2 Key results from Novy-Marx (2007)

64. Firms' log-capacities are initially uniformly distributed between $\log q_0$ and $\log \kappa q_0$. A firm with capacity q redevelops to capacity to κq as soon as prices reach the level P_q^* described on p. 1468.

65. Consider a firm with existing capacity q. From Proposition 7 on p. 1475, immediately before this firm invests it is worth

$$V(q, P_q^*, P_q^*) = \Pi q P_q^* + \frac{\kappa^{\gamma} q^{\gamma}}{(\theta - 1)(1 - \kappa^{\gamma + \theta - \gamma\theta})}$$

and immediately afterwards (when its capacity will be κq) it is worth

$$V(\kappa q, P_q^*, P_q^*) = \Pi(\kappa q) P_q^* + \left(\frac{P_q^*}{P_{\kappa q}^*}\right)^{\theta} \frac{\kappa^{\gamma}(\kappa q)^{\gamma}}{(\theta - 1)(1 - \kappa^{\gamma + \theta - \gamma\theta})},$$

where the constant Π is given in Proposition 3 on p. 1472 and[14]

$$\theta = \left(1 + \frac{1}{\varepsilon_D(\gamma - 1)}\right)\left(\frac{1}{2} + \frac{\lambda - \mu}{\sigma^2} + \sqrt{\frac{2r}{\sigma^2} + \left(\frac{1}{2} + \frac{\lambda - \mu}{\sigma^2}\right)^2}\right).$$

[14]Note that $1/(\gamma - 1) = \varepsilon_S$, the price elasticity of supply (Novy-Marx, 2007, Proposition 1).

In each case, the first term is the value of the firm's assets-in-place and the second is the value of its growth option. The firm incurs capital expenditure of $(\kappa q)^\gamma$, its assets-in-place increase in value by

$$\Pi(\kappa q)P_q^* - \Pi q P_q^* = \Pi(\kappa - 1)qP_q^* = \frac{\theta}{\theta - 1}\kappa^\gamma q^\gamma = \frac{\theta}{\theta - 1}\text{capex},$$

and its growth options fall in value by

$$\frac{\kappa^\gamma q^\gamma}{(\theta-1)(1-\kappa^{\gamma+\theta-\gamma\theta})} - \left(\frac{P_q^*}{P_{\kappa q}^*}\right)^\theta \frac{\kappa^\gamma (\kappa q)^\gamma}{(\theta-1)(1-\kappa^{\gamma+\theta-\gamma\theta})} = \frac{\kappa^\gamma q^\gamma}{\theta - 1} = \frac{\text{capex}}{\theta - 1}.$$

In particular, for each dollar of capital expenditure, the firm's assets-in-place increase in value by

$$M = \frac{\theta}{\theta - 1} = 1 + \frac{1}{\theta - 1}.$$

This is the real option multiplier implied by this model.