INTRODUCING STUDENTS TO THE REAL OPTION
APPROACH TO CAPITAL BUDGETING

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ABSTRACT

The real option approach to capital budgeting has gained acceptance in the business community and is now addressed in Financial Management textbooks and Corporate Finance courses. Real option valuation can be a challenge for both students and instructors. Using two real options examples, a Black-Scholes growth (call) option and a binomial abandonment (put) option, we discuss possible student questions and areas of confusion, potential teaching issues, and basic connections the instructor may need to help students make. We conclude by providing suggestions and a list of resources for facilitating student learning.

Key Words: Capital budgeting, real options, finance pedagogy

INTRODUCTION

For some years now, first level Financial Management[1] textbooks have included an introduction to the real option approach to capital budgeting, often using decision trees to model and value the real options. More recent textbook presentations introduce real options in the chapter(s) covering traditional capital budgeting, and still use decision trees for modeling the real options, but often add a note about the problem of determining the appropriate discount rate when a real option is present in the tree. A later chapter now is dedicated to real options, and here real options are modeled and valued using financial option-pricing techniques, such as the Black-Scholes and binomial option-pricing models, noting that such option-pricing models avoid the theoretical problems inherent in decision tree analyses.

A lack of familiarity with financial option pricing, on either the part of the students or the instructor, then, can make real option valuation a challenge for both the students and the instructor. If students do not have a reasonably strong background in financial option pricing,

the instructor will find it necessary to cover financial option concepts, theory, and pricing techniques before covering the topic of the real option approach to capital budgeting. Even if students do have a reasonably strong background in financial option pricing, the instructor still will find it necessary to conduct a review of financial option concepts, theory, and pricing techniques. On the other hand, if the instructor is not well versed in both financial and real option valuation methods and models, teaching real options surely will be challenging and time consuming.

Further compounding this situation is that, even if financial option theory, concepts, and pricing techniques are covered in a previous chapter, or chapters, a textbook's presentation of the real options approach to capital budgeting may not provide sufficient linkages to financial options for the student to recognize the shared concepts and valuation models. In such cases, the instructor will need to help the students make the connections, theoretical and mathematical, between valuing financial options and valuing real options.

This paper is intended primarily for instructors and explores, on the student side, possible questions and common areas of confusion and, on the instructor side, some of the basic connections she may need to help students make, as well as potential teaching issues she may face[2]. The remainder of this paper is organized as follows. The next section presents a generalized description of the financial option and real option content that, today, may be found in Financial Management (Corporate) textbooks. Section 3 presents two real options decision problems that illustrate some of the potential issues and difficulties students may face when learning about, and the instructor may face when teaching, the real option approach to capital budgeting. The first real option decision problem is a call (growth) option valued using the Black-Scholes model, and the second is a put (abandonment) option valued using the binomial

model. Section 4 concludes with suggestions to textbook authors for modifying and expanding the coverage of real options, suggestions to instructors for facilitating the student learning experience, and list of articles, papers, and books, most of which are not highly mathematical, that may prove helpful for both students learning and those teaching real options.

TEXTBOOK COVERAGE OF REAL OPTIONS[3]

Typically, a MBA level Financial Management textbook has one or two chapters, about in the middle of the book, that cover traditional (DCF) capital budgeting. In these chapters, although the real options approach to capital budgeting may be introduced and explained using decision tree models, the author(s) will note that, when a real option is present in a decision tree, determining the appropriate rate for the tree is problematic.

Later on, after the chapters on capital budgeting, (one or) two chapters cover the concepts and theory of financial options and the basic financial option-pricing models. These chapters define and describe the basic types of financial options (calls, puts), discuss what are the most common underlying assets (stocks, interest rates), and present payoff (or profit) diagrams from both the buyer and seller perspectives for calls, puts, and the underlying asset. The determinants of option value are developed conceptually, and their directional impacts on option value are derived. Discussions of upper and lower bounds on option values may be included. The riskless hedge and risk-neutral approaches to option valuation and the Black-Scholes and binomial option-pricing models are presented. The put-call parity relationship is explored, both conceptually and quantitatively. The textbook author(s) may include discussions of why a traditional DCF model is not appropriate for valuing options and how the option logic can be extended to the firm's debt and to the shareholder's equity.

The chapter dedicated to real options follows, typically directly or soon after, the chapters on financial options. The chapter on real options now presents the real option approach to capital budgeting, and real options are modeled and valued using financial option-pricing techniques such as the Black-Scholes and binomial option-pricing models. This chapter often starts by developing the concept of real options, describing a few of the classical real options, such as a growth option and an abandonment option, and drawing parallels to financial option definitions, constructs, and determinants of value. The concept of managerial flexibility and the need to be able to determine its value is discussed, again noting that the traditional DCF model is not adequate for this purpose. If real options were introduced earlier, the author(s) links back to the prior examples presented, and, if decision trees were used in the chapters on capital budgeting, the author(s) may further explain why decision trees do not properly model volatility when a real option is present. The chapter on real options often ends by describing various business situations having a real option component: growth (call) option, abandonment (put) option, timing (call) option. The valuation model for each decision problem is developed, and the solutions given. The real options valuation models used at the introductory level are, as in the case of valuing financial options, the Black-Scholes and binomial models, but the situation is presented only from the buyer perspective.

TWO REAL OPTION DECISION PROBLEMS

As mentioned above, typically at least one call (e.g., growth, timing) option example and one put (e.g., abandonment) option example are presented in the chapter on real options, and, for each option, an option-pricing valuation model—Black-Scholes or binomial—is developed and solved. For the purposes of this paper, we similarly cover one call decision problem, one put

decision problem, and both the Black-Scholes and the binomial option-pricing models. The first example is of a follow-on product growth (call) option, which we value using a Black-Scholes option-pricing model. The second example is of a new product abandonment (put) option, which we value using a binomial option-pricing model. Although these decision problems are simple ones, they are sufficient for illustrating many of the potential issues and difficulties students may face when learning, and instructors may face when teaching, the real option approach to capital budgeting.

Follow-On Product Growth Option

The Scenario

A conventional growth opportunity (call option) decision problem might be described as follows. A firm is undertaking a project involving the introduction of a new product. The market's reception to this new product is not yet known: the new product could receive a strong market reception, a weak market reception, or anything in between. Future demand, then, is the relevant uncertainty, and it evolves according to a specified process[4]. If it turns out that market demand for the new product is strong, and the new product is highly profitable for the firm, then the firm might consider developing a follow-on product to further capitalize on the first product's market acceptance. In such a case, the firm has a growth option framed as a call option: the firm has the right, but not the obligation, to pay, at some future time, the development and marketing costs to bring the follow-on product to market. This growth option (call option on the follow-on product) will be in the money if the market reception for the first new product, determined over an appropriate introduction period, is sufficiently strong. In such a case, the firm will exercise the call option, develop the follow-on product, and bring it to market. If, however, demand turns

out to be not sufficient, the firm will allow the call option to expire, and not pursue a follow-on product.

In practice, examples of such follow-on products abound. Once there was Godiva chocolate—candy, that is. Now there is Godiva chocolate hot cocoa and Godiva chocolate coffee. Barbie preceded Ken to market. Red ketchup went to green ketchup, and now we have blue ketchup as well. Not so long ago, none of the car manufacturers made SUVs, let alone multiple models of SUVs. R&D inherently is a staged process where each step contains a call option on the next step: continue on with development if the current step is successful. A new drug is brought to market only if the development is successful and the clinical trials show the drug to be effective and safe.

Option Valuation

A Black-Scholes option-pricing model may be used to value a follow-on product opportunity framed as a growth (call) option. When using a Black-Scholes model, option value is determined in one of two typical, yet very different, ways. The first way is by determining the values of the required option-pricing factors and then solving for the call value by entering the values into a spreadsheet or software program. In this case, the spreadsheet or software program actually determines option value. The commonly required option-pricing factors are (1) the current (present) value of the underlying asset, (2) the exercise price, (3) the time remaining until the option expires, (4) the standard deviation of the returns to the underlying asset, and (5) the risk-free rate of return for the holding period. These option-pricing factors for the follow-on product opportunity are defined in Table 1. After getting the option value, the decision-maker (i.e., the student) is asked to make a yea/nay decision about the project (e.g., the first new

product), or about mutually exclusive projects, taking into consideration the resulting value of the (e.g., follow-on product) real option.

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Place Table 1 about here

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The second way Black-Scholes real option value typically is calculated is by algebraically solving the Black-Scholes call option equation. This requires first determining the values of the exact same set of required pricing factors listed above. So this step is common to both approaches. But, in this second way, the pricing factors then are used to determine the appropriate Black-Scholes d_1 and d_2 variables, which are, themselves, then used to obtain the Black-Scholes $N(d_1)$ and $N(d_2)$ probabilities. Given the determined pricing factors and the $N(d_1)$ and $N(d_2)$ probabilities are the inputs to the standard Black-Scholes call option equation, the real option value now can be solved for algebraically. After calculating the option value, the decision-maker (i.e., the student), as previously, is asked to make a yea/nay decision about the project (e.g., the first new product), or about mutually exclusive projects, taking into consideration the resulting value of the (e.g., follow-on product) real option.

Student Questions and Areas of Confusion

Using the Black-Scholes option-pricing model for modeling and valuing the follow-on product opportunity as a real option will certainly raise issues for the student[5]. On a business strategy level, obvious limitations with using a Black-Scholes model as described are that the growth option is modeled as a European call option with no dividends or loss function. Such a model says that the firm has the right to do the follow-on product only at one specific future

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time, and yet, while waiting, the firm does not lose any expected revenue from the follow-on product nor does a competitor bring a similar product to market. This business situation is easily challenged. Students also are likely to wonder how the firm acquires the growth option, and at what cost, and they generally need help understanding the timing of events as well. For example, the growth option is valued as of when it is acquired, which is when the firm undertakes the first new product. Thus, the present value of the underlying asset is as of time 0, and not as of the end of the new product introductory period, time "t".

On a mathematical level, if a spreadsheet or software program approach is used, students are likely to struggle with the "black box" phenomena. Although typically the present value of the underlying asset is given (i.e., it is assumed known), which indeed simplifies the analysis, doing so introduces an additional "black box" issue. Similarly with the standard deviation. Although a critical determinant of option value, and one that is difficult to determine in practice, it usually is simply given. If the second approach, the algebraic solution approach, is used, many students will struggle with the math, and the focus will shift from understanding real option valuation to performing algebra calculations.

How the current (present) value of the underlying asset is presented in the decision problem can lead to technical questions from the students. If the problem description simply states what is the current value of the underlying asset (i.e., it is assumed known), students rarely understand that the current value of the underlying asset is the present value of the free cash flows the firm expects to receive from the follow-on product over its economic life, and, therefore, the capital expenditure required to bring the follow-on product to market is not included. That is, the current value of the underlying asset is determined on the basis of present value rather than net present value. To date, students probably have not seen the cost of a project

handled independently. Yet, here, the cost is the exercise price, and it must be separated out from the rest of the follow-on product's free cash flows.

If, however, the present value of the underlying asset is not given, then it must be determined, and doing so requires that the risk adjusted discount rate for the follow-on product be given, or that an equilibrium asset-pricing model exists for determining the expected rate of return. One often stated benefit of option pricing is being able to use the risk-free rate of return, and not having to determine the risk adjusted discount rate for the underlying asset. This benefit only exists if the current value of the underlying asset is given. In addition, having to determine a discount rate for the underlying asset leads squarely to the question of why a risk-adjusted discount rate is used for determining the present value of the underlying asset when the option, itself, is valued using a risk-free rate. It is true that options can be valued using risky probabilities and risky rates, and, when doing so, the discount rate increases for calls and decreases for puts. This is because asymmetric claims on an asset do not necessarily have the same expected rate of return as that of the underlying asset alone. Moreover, when valuing using risky probabilities and risky rates, the volatility, or appropriate discount rate, changes each time the price of the underlying asset changes. Understanding such effects is surely a higher order notion, both conceptually and mathematically.

A subsequent technical question might be if the Black-Scholes option-pricing model says that the return the firm expects to achieve from this option is the risk-free rate of return. Bringing a follow-on product to market surely is a risky venture, and the option on the follow-on product, being a levered position, is even riskier, so the firm must want to be paid a risk premium compensating it for bearing the risk. The question of which risk-free rate of return is appropriate to use when valuing the option, and why, also may surface at this time.

A related question is why the capital expenditure in a traditional DCF analysis, if not occurring immediately (i.e., occurring after time 0), usually is discounted at the risk-adjusted discount rate for the underlying asset, whereas the exercise price for the option is discounted at the risk-free rate. Since the capital expenditure and the exercise price are the same construct, is this not inconsistent treatment?

An advanced student also might question using the standard deviation of the returns to the underlying asset as the measure of risk, and struggle with the notion that an increase in volatility increases option value. After all, the student has been taught that total risk (standard deviation) is not the appropriate measure of financial risk, but rather that systematic risk (beta) is the relevant measure of risk, and that an increase in uncertainty decreases value. The overarching new concept here is that of derivative assets—assets that derive their value from the value of other assets.

Again, on a business strategy level, students, being mired in the mathematics and the technical issues, may not immediately see that when a firm undertakes an investment opportunity, it really exercises the associated call option, and that the firm loses the value of waiting for further information. Students may completely miss that the real options approach to capital budgeting is all about deferring decision-making to allow uncertainty to resolve, at least to some extent, so that the firm's decision-making can be more informed. Similarly, students may miss questioning the likelihood that the option will be valuable, and that the likelihood of the option being valuable is important. Whether the likelihood is small but the value great or whether the likelihood is great but the value small really should be considered in any investment decision-making. And finally, even an advanced student may struggle with the notion that a firm may rationally undertake a negative NPV project in order to acquire an option on a second

project that has an expected negative NPV. This notion is contrary to, and, in fact, the reverse of, the traditional DCF guiding principal.

New Product Abandonment Option

The Scenario

An investment provides the firm with a claim to a cash flow stream generated by the project's assets (i.e., the assets in place (AIP)). Sometimes, however, the firm also has the opportunity to "put" the project back to the market (i.e., a put option on the AIP). To determine the course of action having the highest value in such a case, the firm must compare the value of the cash flow stream from continued operations with the one from abandoning the project and selling off the project's assets.

For our abandonment decision problem, we take the follow-on growth decision problem and make a few changes. The firm still is introducing a new product to the market, and the market's reception to this new product is not yet known. Future demand, then, still is the relevant uncertainty, and it still evolves according to the same specified process as before. Now, however, future demand can only take one of two states—strong or weak—and nothing in between, and demand will stay strong or weak from then on.

In addition, the follow-on product is no longer part of this abandonment decision problem, and the focus changes from the firm taking advantage of its upside potential to protecting its downside. That is, if events unfold such that market demand for the new product is weak and not sufficient for the new product to be profitable, the firm can, if it is able to and allowed to, terminate the project and stop producing the new product. In this case, the firm has an abandonment option framed as a put option: the firm has the right, but not the obligation, to

receive, at some future time, a cash payment from terminating the project and selling off the project's assets. The put option for the assets invested in the new product project will be in the money if the market reception for the new product, determined over an appropriate introduction period, is sufficiently weak such that the value of the cash flow from abandonment is greater than the time "t" present value of the cash flows from continuing. In such a case, the firm will exercise its put option by terminating the project and selling off the project's assets. If, however, demand turns out to be strong, and the product is profitable for the firm, the firm will allow its put option to expire, and will continue producing and marketing the new product.

As with follow-on product examples, in practice, discontinued product examples abound. Such examples, however, may be harder to remember if the products were not in the market place for a long period of time. Classic examples include New Coke and the Edsel. Another example can be found in cellular technology history. In the 1950's, AT&T originally developed wireless phone technology, but, as the story is told, AT&T did not think the technology had any viable commercial applications. So AT&T not only chose not to exploit the technology, but also chose not to sell the technology (i.e., did not exercise its abandonment option). The story does not end there, however. Again in the 1980's when regional cellular licenses were being granted, AT&T did not act. AT&T finally entered into the cellular business in 1994 when AT&T acquired McCaw cellular, which exercised its put option on the (whole) firm.

Option Valuation

A binomial option-pricing model may be used to value an opportunity to terminate a project framed as an abandonment (put) option. When using a binomial model to value a real option, the option's value may again be determined either by using a spreadsheet or software

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program or by algebraically computing the value. The pricing factors for the binomial model are, for the most part, the same as for the Black-Scholes model. The one exception is that the standard deviation of returns to the underlying asset (σ) is often replaced by the binomial lattice model's up (u) and down (d) parameters, although σ is directly related to u. A proper binomial model converges, in the limit, to a Black-Scholes model, and one connection between the two models is the following relationship.

$$u = e^{(\sigma\sqrt{\Delta t})} \tag{1}$$

Additionally, for a symmetrical lattice, the down parameter (d) is the inverse of the up parameter (u), and, thus, d is indirectly related to σ when the lattice is symmetrical. The option-pricing factors for the new product abandonment option are defined in Table 2. As with the previous growth option decision problem, after getting the put option's value, the student is then asked to make a yea/nay decision about the project, or about mutually exclusive projects, considering the resulting value of the real option.

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Whether using a spreadsheet or software program to compute option value or computing option value algebraically, the pricing factors first need to be determined. The following process assumes a one period binomial.

Step 1: Determine the time "t" value of the remaining state dependent cash flows to the new product assuming a strong market reception (S^+) and assuming a weak market reception (S^-).

Step 2: Determine the current value of the underlying asset (S).

a. If the present value of the underlying asset is given, simply identify it.

b. If the present value of the underlying asset is not given, then, as with the Black-Scholes option-pricing model, "S" must be determined. Doing so again requires that either the risk-adjusted discount rate (RADR) for the project be given or that an equilibrium asset-pricing model exists for determining the underlying asset's expected rate of return. Here, however, determining present value also requires that the subject probabilities of strong demand (q) and weak demand (1-q) be given. Then the present value of the underlying asset is determined by discounting the *expected value* of the underlying asset as of the end of the introduction period (time "t") by the appropriate risky discount rate.

$$S = [q\ (S^+) + (1\text{-}q)\ (S^-)]\ /\ (1\text{+radr}) \qquad (2)$$

Step 3: Determine the time "t" expected value of the cash flow the firm would receive from terminating the project and selling off the project's assets (X).

Step 4: Determine either the binomial up (u) and down (d) parameters or the standard deviation (σ) of the expected returns to the new product.

a. Compute the binomial parameters.

$$u = S^+/S \qquad (3)$$

$$d = S^-/S \qquad (4)$$

Note: u and d are related as follows when the lattice is symmetrical.

$$d = 1/\ u \qquad (5)$$

b. If a given spreadsheet or software program specifically asks for the standard deviation, and assuming the lattice is symmetrical:

   i. If the standard deviation (σ) is given, simply identify it.

   ii. If the standard deviation is not given, compute the binomial up parameter u (Step 4.a), and then back out sigma from the following equation.

$$u = e^{(\sigma\sqrt{\Delta t})} \quad (6)$$

Step 5: Determine the risk-free rate or return (r) for the holding period of the option.

At this point, the required pricing factors can be entered into a spreadsheet or software program or the value of the option can be computed algebraically. To compute the option value algebraically:

Step 6: Determine the risk-neutral, often called "pretend", probabilities of strong demand (p) and weak demand ($1-p$) under the assumption that the weighted-average expected return to the project must equal the risk-free rate for the holding period of the option. That is, assume that the law of one price holds, and that the value derived using subjective probabilities (q and ($1-q$)) and a risky discount rate (RADR) must equal the value derived using risk-neutral probabilities (p and ($1-p$)) and the risk-free rate (r).

$$S = [q\ (S^+) + (1-q)\ (S^-)] / (1+radr) = [p\ (S^+) + (1-p)\ (S^-)] / (1+r) \quad (7)$$

The above equation reduces to the following equation, which is the equation most commonly presented and used for determining the risk-neutral probability p.

$$p = [(1+r) - d] / (u - d) \tag{8}$$

Step 7: Determine whether the option will be exercised in either of the resulting

demand states, and then determine the time "t" option value for each state

of demand.

$$\text{Max } (X- S^+, 0) \text{ and Max } (X- S^-, 0) \tag{9}$$

Step 8: Compute the expected value of the abandonment option as of the end of

the new product's introductory period (time "t") by applying the risk-

neutral probabilities (p and ($1-p$)) determined in Step 6 above to the

option maturity values determined in Step 7 above, respectively.

Step 9: Finally, discount the expected value of the option at the risk-free rate for

the holding period to find the present value of the abandonment option.

Student Questions and Areas of Confusion

The possible student questions and areas of confusion previously mentioned in regards to

the Black-Scholes model (the follow-on product growth option), may also surface when using a

binomial model for valuing a real option. Yet other questions and areas of confusion specifically

related to the binomial model itself may surface as well. Moreover, the binomial model is less of

a "black box" than is a Black-Scholes model, so using a binomial lattice to model and value a

real option may actually provide a greater number of questions from the student[6]. On the other

hand, in contrast to the Black-Scholes model, the typical student likely will be able to follow the

math required to solve a binomial model, and may be able to mimic the solution for similar

problems.

The typical student likely will not be able to understand the application of the binomial method to the business situation, even if the student has recently been exposed to the same solution process for financial options. From a business perspective, a reasonable question is that of why only two future states of demand _can_ occur. In addition, the application of risk-neutral probabilities to a real world investment project will not seem reasonable, especially if subjective probabilities are also estimated. Students often seriously struggle with such "pretend" probabilities: what they are, what is their exact meaning, and why have they been calculated using a risk-free rate. Furthermore, using a risk-free rate of return when valuing the option will, again, as with a Black-Scholes model, surface the question of why the time "t" option values are discounted at the risk-free rate, since the option must have a risky component. A related issue is that the appropriate risk-free rate is the one for the holding period. For a binomial lattice, one period could be one year, but one period could also be less than or more than one year. If one period does not equate to one year, the risk-free rate will need to be adjusted for the holding period. The concept, derivation, and use of risk-neutral probabilities in association with discounting at the risk-free rate for the holding period are commonly difficult for the student to master, even if the student has had a good foundation in financial option pricing. Thus the instructor acquires not only the task of presenting the process of valuing a real put option using a binomial model but also those of making the connections between financial and real options and of describing and justifying the applicability of the real options approach to capital budgeting to the investment opportunity. These tasks are made even more difficult if those teaching real options also struggle with the same issues and questions.

A discerning student again may question why a standard DCF model is not used to determine the value of the project. This is especially likely as the binomial model is less of a "black box" and requires the student to "map out" the cash flows. That is, why not simply:

1. If the optimal choice is to continue producing and marketing the new product, compute value the future expected free cash flows to the new product;

2. If the optimal choice is to discontinue production of the new product, substitute the time "t" value of the put option as the value of the going concern; and

3. Discount the cash flows using the standard subjective probabilities and at the appropriate risk-adjusted discount rate for the project.

Although why a DCF model is not sufficient for valuing options was doubtless discussed in previous chapters, the student may not sufficiently understand the underlying concept to be able to make the transition from financial options to real options or from one application to another. Moreover, the binomial model now specifically shows the capital expenditure or exercise price being incurred at a future time, and this may raise the issue of this cash flow probably not being deterministic.

Mapping out the cash flows in the lattice is almost certainly the first time the student has been required to specifically model uncertainty and directly computed expected values of free cash flows. The idea of a probability distribution—up (strong demand) and down (weak demand)—being behind the expected value will need to be developed.

Similar to the question related to the Black-Scholes model—Why is the current value of the underlying asset determined on the basis of present value rather than net present value?—the question related to the binomial model is, "Why are the returns for the possible outcomes determined on the basis of value rather than on cost or net present value?"

At the time of valuing the option to abandon the project, the firm has not even decided to implement the project and certainly has not started the project. Yet the put option is valued as if the firm already has the project in place (i.e., owns the underlying asset). A common student question is, "When modeling an abandonment option, why do I have to 'own' the project already? I do not already own it."

Finally, and unfortunately, the decision made about the investment, or mutually exclusive investments, may be shrouded once the put option is valued and given the student questions and concerns. Moreover, textbooks tend to focus more on determining value than on the decision-making process. The instructor must be prepared to discuss how a decision about the investment is made once the put option is valued, without the question being poised by a discerning student.

SUGGESTIONS AND RESOURCES

Suggestions To Textbook Authors

Both students learning and instructors teaching the real options approach to capital budgeting would be helped if the textbook authors modified and expanded, to some degree, real options coverage. The following suggestions are made with this in mind.

Suggestion #1: Add a transition chapter between the financial option pricing chapter(s) and the real options chapter, where the real options approach to capital budgeting is specifically, and in detail, developed. For the core (survey) Finance course, the instructor may choose to include this chapter and not the following chapter where the technical analyses are presented. That is, it may be sufficient to cover the concepts and purpose of real options and not the pricing models.

This chapter could start by discussing how a firm acquires a real option and the rationale for modeling projects as real options: deferring decision-making until uncertainty resolves, to some extent, so that the firm can make a more informed decision. Also, the cost to waiting needs to be seriously addressed. The chapter could address what it means for an asset to be a derivative asset, and what implications this has for valuing both the underlying asset and the derivative asset, and then make the links, and draw the parallels, for example, between a stock as an underlying asset and a project as an underlying asset. A discussion of why only the free cash flows the underlying asset is expected to generate over its life are used to determine the present value of the underlying asset and that the cost is now the exercise price and excluded would help drive home the separation required for real options analyses.

Also, it is critical that the difference between alternatives and options, or between alternatives and options embedded in a project, be explained. As with a traditional DCF analysis, if you are given all the inputs, getting the value is nothing but a plug and chug exercise. The real trick to any asset valuation is to appropriately determine and model the inputs; and it is no different with the real option approach to capital budgeting. One theme that has consistently surfaced in the real options literature is the fundamental, yet vital, role project framing plays in setting up a real options analysis.

Suggestion #2: Give all data for a given problem so that the instructor can show the full solution process, make the conceptual and mathematical links between the different option-pricing models, and illustrate that the option value obtained is the same regardless of which option-pricing model used. For example, do not just give the value of the underlying asset today; rather also give the node ending cash flow values, or even the node-ending cash flow streams, the cost, the subjective probabilities, and the risky discount rate. Then the instructor can develop

and explain the linkages between the various option-pricing models, and even show how a traditional DCF analysis results in an incorrect project value and project choice.

Suggestion #3: The examples in the texts are generally relatively straightforward, limited in scope, and simplified or structured to meet option pricing assumptions and requirements, often ignoring the many complexities found in real options analyses in practice. For example, the decision problem generally is only a one period, 2-state problem and the present value of the underlying asset and the expected cash flows, or returns, for each state are given. In addition, the real option is presented individually, and not as one part of a project having both traditional DCF type free cash flows and option-like free cash flows. Although such a presentation may be appropriate for an introduction, a thorough discussion of what real options in the real world might look like, as well as how they may violate the option pricing modeling assumptions, would be welcomed. Another welcomed discussion would be of how to deal with multiple uncertainties, or multiple real options in one project.

Suggestions To Instructors

Regardless of the textbook used and the extent that any of the suggestions above are incorporated into the textbook, the instructor can facilitate the student learning experience. To that end the following suggestions are made:

Suggestion #4: The pricing techniques used in valuing real options are, by and large, more easily applied to financial options. The students may benefit, then, from the instructor reviewing the parallel financial option-pricing model with each real option decision problem. The review should be beneficial since, for many students, financial option techniques were just

recently taught, and, therefore, expecting complete recall of financial option pricing in order to concentrate on real option valuation may be shortsighted.

Suggestion #5: The financial option concepts are perfectly adaptable to real options, but the financial option techniques are not. Implementation often is a real challenge. So, as suggested above to textbook authors, a frank admission of this relationship by the instructor may be helpful. If the student is told that using financial option techniques to value real options is somewhat akin to "placing a square peg in a round hole" (it at least feels up the space), the student may be more willing to accept using a technique that seems questionable. Then the student also may be able to explore the insight that real options can bring to the business situation at hand. The instructor may find this a perfect time to discuss that capital budgeting procedures using DCF techniques also may involve seemingly intractable difficulties, and that all capital budgeting—DCF models and real options models—is a best guess proposition with a wide confidence interval around the resulting value. We can be precise, but rarely can we be accurate. A CEO once said that he just wished he could get his project valuations within plus or minus $5 million of actual value.

Suggestion #6: According to Finance, the value of any asset is the present value of the cash flows the asset is expected to generate. This is a principle that is applicable to any and all assets. The more the instructor relates real option valuation to the valuation of other assets, then the better the student will understand that finance valuation principles and models are generalizable. For example, the instructor can review the concept that stock prices relate to the expected future cash flows from a set of firm assets.

Suggestion #7: One of the hardest tasks the instructor has is stopping the students from getting absorbed and lost in the technical details so that they can develop an understanding of the

underlying message about the connection between real options and strategic decision-making. In this regard, the rational for the use of financial option-pricing techniques emphasizes the strategic decision-making process. The professor also should emphasize that a real option provides the firm with an option not an obligation. This is a perfect situation in which to make this emphasis. For instance, in both the follow-on option and the abandonment option, the decision is different because the option allows the firm to ignore part of the return distribution. The growth option is valuable for a follow-on project even if the expected value of the distribution of the NPV for the follow-up project is negative at the time of the investment in the initial project. The call option has value because it allows the firm to ignore the negative part of the distribution. Again, real options are all about deferring decision-making until uncertainty resolves, to some extent, so that the firm can make a more informed decision.

Resources

We conclude by providing a list of articles, papers, and books, most of which are not highly mathematical, that we personally have found valuable in our own efforts to learn and teach real options. Our hope is that these will prove to be helpful resources for both students learning and those teaching real options. We also would like to note that these are just a few of the many real options articles, papers, and books that have been published or are available on the internet.

Real Options—Primarily Qualitatively

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Financial Option-Pricing Techniques

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S. Mason. "Introductions to Options," Harvard Business School Teaching Note (9-286-104), (1986, Rev. May 20, 1996).

Real Options—Primarily Quantitatively and Applied

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Lander, D. M. "Do Foregone Earnings Matter When Modeling and Valuing Real Options?: A Black-Scholes Teaching Exercise," <u>Financial Practice and Education</u>, 10 (Fall-Winter, 2000), 121-127.

Leslie, K. J. and M. P. Michaels. "The Real Power of Real Options," <u>McKinsey Quarterly</u>, 3 (1997), 4-22.

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Mahajan, A. "Pricing Expropriation Risk," <u>Financial Management</u>, 19 (Winter, 1990), 77-86.

Morris, P. A. E. O. Teisberg and A. L. Kolbe. "When Choosing R&D Projects, Go With Long Shots," <u>Research–Technology Management</u>, 34 (Jan-Feb, 1991), 35-40.

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Journal Issues Dedicated to Real Options

<u>Academy of Management Review</u>, 29 (Jan, 2004).

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<u>Financial Management</u>, 22 (No. 3, 1993).

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More Mathematical or Advanced

Black, F. and M. Scholes. "The Pricing of Options and Corporate Liabilities," <u>Journal of Political Economy</u>, 81 (May-Jun, 1973), 637-654.

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END NOTES

1. The focus of this paper is on the MBA core (survey) Finance course and the intermediate level Corporate Finance course, and, thus, a Financial Management (Corporate) textbook would be commonly used.

2. Cromwell and Hodges [1998, in Resources list above] also address teaching real options, and present examples and provide teaching notes. Their focus, however, is on presentation methods and option modeling solutions. In contrast, our focus is on student questions, comprehension, and learning.

3. See Cromwell and Hodges [1998, in Resources list above] Tables 1, 2, and 3 for a summary of the real option coverage in the most commonly used Financial Management and Corporate Finance textbooks.

4. Because option-pricing techniques do not predict future values of the underlying asset, future values are assumed to follow some given well defined process. An asset whose value randomly changes over time is said to follow a stochastic process—continuous or discrete. Continuous-time option-pricing models generally assume the value of the underlying asset follows a lognormal distribution or that returns are normally distributed. Changes in asset value are thus modeled as a geometric Brownian motion (GBM) where μ is the known and constant expected rate of return, where σ is the known and constant volatility, and where uncertainty is represented by a standard wiener process (dz): $dS = \mu S dt + \sigma S dz$. A binomial option-pricing model assumes the value of the underlying asset follows a multiplicative binomial, assumes the up and down parameters and the volatility of the underlying asset (σ) are constant and known, and uses risk-neutral probabilities for valuation. Knowing the current value and the mean and standard deviation of the associated probability distribution, the analyst can forecast the asset's future value, which is the key to determining an option's value at expiration.

5. Many of the student questions and areas of confusion are fundamental option pricing questions and not specific to real options, but rather just in the context of a real options application.

6. As with the growth (call) option, many of the student questions and areas of confusion related to an abandonment (put) option are fundamental option pricing questions and not specific to real options, but rather just in the context of a real options application.

TWO TABLES

Table #1

Table 1: Pricing Factors for the Follow-On Growth Option
S   the current value of the underlying asset—the present value, as of the time the firm acquires the growth option, of the free cash flows the firm expects to receive from the follow-on product over its forecasted economic life;
X   the exercise price—the development and marketing costs the firm would incur to bring the follow-on product to market;
t   the time to expiration—the time until the market reception of the first product is sufficiently known such that the decision regarding the follow-on product can be made;
σ   the standard deviation of the expected returns to the follow-on product; and
r   the risk-free rate of return for the holding period of the option (i.e., from the time the firm acquires the follow-on product option to time "t").

Table #2

Table 2: Pricing Factors for the New Product Abandonment Option

S   the current value of the underlying asset—the present value, as of the time the firm acquires the put option, of the free cash flows the firm expects to receive from the new product *after* the introduction period;

X   the exercise price—the time "t" expected value of the cash flow the firm would receive from terminating the project and selling off the project's assets;

t   the time to expiration—the time until the market reception of the new product is sufficiently known such that the decision regarding project termination can be made;

u   the binomial up parameter—the ratio of the time "t" value of the remaining state dependent cash flows to the new product given strong market reception (S^+) to the current value of the underlying asset (S);

     and

d   the binomial down parameter— the ratio of the time "t" value of the remaining state dependent cash flows to the new product given weak market reception (S^-) to the current value of the underlying asset (S);

     or

σ   the standard deviation of the expected returns to the new product; and

r   the risk-free rate of return for the holding period of the option (i.e., from the time the firm acquires the abandonment option to time "t").