VOLUME 17 | NUMBER 2 | SPRING 2005

Journal of APPLIED CORPORATE FINANCE

A MORGAN STANLEY PUBLICATION

In This Issue: Real Options and Corporate Strategy

Morgan Stanley

Realizing the Potential of Real Options: Does Theory Meet Practice?

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The Annual Real Options Conference, now in its seventh year, has been a useful forum for the exchange and debate of new ideas about corporate strategy and valuation. The tag line for the conference, "Theory Meets Practice," reflects the goal of bringing together academics and practitioners to explore new approaches for making capital investment decisions and adapting such approaches for practical application. And given the presence of both academics and practitioners in this audience, a natural topic for my talk today comes from simply transforming the tag line into a question, "Does Theory Meet Practice?" Is the gap between theory and practice closing, and what can we do to speed this up?

The idea of viewing corporate investment opportunities as "real options" has been around for more than 25 years—in fact, it dates back to Stewart Myers' use of the phrase in his well-known 1977 article.[1] Since then, the idea has had a huge impact on academic research. Based on a literature database that I've maintained since the late 1990s, I estimate there are now nearly 1,000 research papers that incorporate real options ideas.[2] Real options concepts and techniques have not only become prevalent in research in finance and economics, but have also more recently influenced research in virtually every business discipline, including strategy, organizations, management science, operations management, information systems, accounting, and marketing. Real options has thus become a truly cross-disciplinary area of research, with great potential to improve corporate decision-making while promoting better understanding of the role of uncertainty on investment activity in various sectors of our economy.

Given this wide acceptance and activity in academia, one might expect commensurate interest in the practitioner realm. Real options has indeed been used by many companies in evaluating investment opportunities and associated risks, and many managers can point to improvements in decision-making as a result of adopting real options. But even so, the extent of acceptance and application of real options today has probably not lived up to the expectations created in the mid- to late-1990s, when real options first began to take hold at a broad cross-section of companies.

In their 2001 survey of the CFOs of some 400 Fortune 1000 companies, John Graham and Campbell Harvey reported that about a third of the CFOs said they "always" or "almost always" use real options when evaluating new investments.[3] But in another recent survey of Fortune 1000 CFOs, the authors reported a significantly smaller fraction of CFOs—around 10-15%—using real option techniques "always" or "often."[4] And a survey conducted by Bain & Co. in 2000 found that only 9% of the senior executives polled had used real options.

Much of the differences in these survey findings could reflect differing interpretations of the term "real options." In an interview-based survey of 40 corporate managers that I conducted with Adam Borison in 2001, we found that there were indeed significant differences in the ways in which managers were using real options in their organizations. For many firms, real options served primarily as a conceptual tool for strategic planning and framing of decision problems. However, for the majority of firms in our sample, real options valuation techniques, ranging from simple to very rigorous, were being used to evaluate investment opportunities.[5]

Regardless of the exact numbers, it appears that many companies have incorporated real options analysis to varying degrees into their decision-making processes. Even a 10-20% adoption rate over the period of a decade may be quite promising, given the very gradual acceptance of other corporate decision-making techniques, including NPV. Nevertheless, the question remains whether the initial rate of corporate adoption of real options is sustainable. If early successes have led to positive feedback within and across

* This article is based on my keynote address at the 7th Annual International Conference on Real Options held at the McDonough School of Business, Georgetown University, July 10-12, 2003.

1. Stewart Myers, "Determinants of Corporate Borrowing," *Journal of Financial Economics*, Vol. 5 (1977), pp. 147-175.

2. This database is available at www.rhsmith.umd.edu/finance/atriantis, and can be searched based on author name, keywords, journals, or date.

3. John Graham and Campbell Harvey, "The Theory and Practice of Corporate Finance: Evidence from the Field," *Journal of Financial Economics*, Vol. 60 (2001).

4. Patricia and Glenn Ryan's survey of 205 Fortune 1000 CFOs found that, at the 75th percentile level (categorized as "always or often"), 1.6 % of the CFOs used Real Option techniques, 5.3% used Option Pricing techniques, 7.6% used Complex Mathematical Models, and 7.9% used Decision Trees. All of these categories overlap somewhat or completely with real options analysis. For example, the category "complex mathematical models" included real options models. For further details, see Patricia Ryan and Glenn Ryan, "Capital Budgeting Practices of the Fortune 1000: How Have Things Changed?," *Journal of Business and Management* (October 2002).

5. Further distinctions in the way that real options analysis is implemented in different organizations are discussed in Alex Triantis and Adam Borison, "Real Options: State of the Practice," *Journal of Applied Corporate Finance* (Summer 2001).

corporations, one would expect the trend to continue. But there is at least one sign that this may not in fact be the case. The Bain survey in 2000 found a very high defection rate (32%) among those senior executives who said that they had used real options. Though this is the only, and perhaps unreliable, statistic we have that might help us calibrate the trajectory of real options adoption, it does not bode well. It is certainly cause to pause and reflect on why theory may not in fact be meeting the needs of practice.

I will begin by discussing some of the key successes of real options to date. Next I will present some critiques of real options raised by practitioners. This will lead in turn to a proposed research agenda, based on five key themes, that I believe can help bridge the current gap between theory and practice.

New Insights and a New Vocabulary

The interest in real options has helped to focus corporate managers' attention on the value of flexibility. Specifically, in planning a company's investment and operating strategies, managers are increasingly aware that they can respond to new information over time, and that this kind of flexibility affects not only their future decisions, but also their present ones. Viewing corporate strategy in a real options framework is likely to make management both more *reactive*, in the sense of responding effectively as uncertainties are resolved over time, and more *proactive* in building flexibility into projects.

What kinds of strategic insights and recommendations come from viewing projects in this more dynamic framework?

Some of the earliest and best-known insights stem from our knowledge of the pricing of financial options. For example, financial options that are "out-of-the-money"— those where the cost of purchasing the underlying asset is greater than the value of the asset—often sell at high premiums based on the possibility that the asset value could increase beyond the exercise cost before the expiration date. By analogy, corporate real investment opportunities that appear unprofitable when managerial flexibility is ignored in the evaluation analysis *often* have positive value when viewed as growth options—options that can be exploited if and when underlying value drivers, such as input and output prices, move in a profitable direction. For this reason, early-stage projects—or companies that are burning cash and may even have dubious long-term potential under the most likely scenarios—may still have considerable value owing to the possibility of future favorable events, particularly if the underlying uncertainty is large.

A second important lesson from financial options is that growth options that are "in-the-money" (that is, the investment outlay is lower than the present value of the project) are often best left unexercised at the current time. The key insight here is that unfavorable investment situations can be avoided by waiting, and this potential benefit may outweigh the loss due to foregone profits or competitor entry.

While knowledge of these basic facts about options has influenced managerial decision-making, the real impact on shareholder value creation has come more from a change in the corporate mindset about uncertainty and risk. Rather than treating risk as something to be avoided, real options thinking encourages managers to view volatility as a potential source of value, with profound implications for the design of projects and corporate strategy. For example, valuable options can be created in a variety of ways:

- by dividing up large projects into a number of stages;
- by investing in information acquisition or production;
- by introducing "modularity" in manufacturing and design;
- by developing competing prototypes for new products; or
- by investing in infrastructure that provides a platform for potential future growth.[6]

In general, the concept of strategic foresight has become more formalized as managers focus less on the "most-likely" scenario and more on the distribution of possible outcomes, taking explicit account of the uncertainties that lie ahead and incorporating flexibility into project design in order to respond to future events. In addition to restructuring R&D, manufacturing, and supply chain processes, managers now consider "selling" flexibility by providing customers with options that they value more than the firm's cost of providing them.[7]

From a risk-and-return perspective, there is also growing recognition that the risk profiles of projects differ considerably based upon whether the projects are early-stage investments in creating options or later-stage expenditures that involve exercising options to complete investment in a project. Furthermore, as suggested above, the real options mindset forces corporate managers to consider more carefully the opportunity cost of investing. For instance, by choosing to invest in new technology infrastructure today, the firm may be passing up the opportunity to invest in a potentially superior, but mutually exclusive, technology in the near future.

These insights seem to resonate with corporate management. Many managers view the insights that emerge from

6. I provide further examples and detail in A. Triantis, "Creating and Managing Shareholder Value: A View through a Real Options Lens," in *Real Options and Business Strategy: Applications in Decision Making* (London: Risk Books, 1999), pp. 39-58. For an example of the value of modular plant design, see Tom Copeland and Vladimir Antikarov, "Meeting the Georgetown Challenge," *Journal of Applied Corporate Finance*, this issue.

7. For instance, Dell and HP have built flexibility into their supply chain systems that allows customers to configure their own hardware; see my article with Corey Billington and Blake Johnson, "A Real Options Perspective on Managing Supply Chain Risk in High Technology," *Journal of Applied Corporate Finance*, Vol. 15, No. 2 (Winter 2003).

the options analogy as confirming, and perhaps further honing, their instincts, while others find that these insights transform the way they plan and operate at their level of the organization. In fact, a common tendency of managers on first becoming acquainted with the concepts is to see "real options everywhere." And over time, such managers also generally develop an options-based, shorthand vocabulary that does a better job of communicating strategic objectives internally and, in some cases, to the firm's shareholders and the analyst community.

The Search for Killer Aps

Any new technology needs "killer aps," applications that are particularly well suited for the technology and thus help to "sell" the tool in practice. In the case of real options, the first major area of application was in valuing investments in the exploration and development of natural resource reserves, particularly minerals and oil and gas. But the range of applications has increased considerably, particularly in the last decade. The use of real options to evaluate research and development programs has spread well beyond the energy and mineral industries. The pharmaceutical industry and, indeed, the entire life sciences area, together with the technology industry, have provided many examples of successful implementations of real options. Real options analysis is also frequently used in operations management in manufacturing and power generation, especially in capacity planning and the evaluation of operating flexibility. More recently, real options tools have been applied in valuations of various kinds of corporate restructurings, including mergers and acquisitions, joint ventures, and divestitures, and in the planning of infrastructure investments, both brick and mortar as well as IT.

These main applications have some common features that make them particularly well suited to—and often most in need of—real options analysis. They all involve significant up-front investments that often don't lead to immediate cash flows. They also tend to have well-defined stages where the framing of the problem can be logically laid out and where there are major, well-defined sources of uncertainty whose resolution is expected to contribute significantly to the outcome and ultimate value of the projects. In addition, in most cases, data is readily available to estimate key parameters of the model. In the case of natural resources, for example, this data comes directly from financial markets, such as futures and options markets. Real options can also be modeled more accurately in firms that have proprietary opportunities, such as the right to develop a piece of physical or intellectual property, yet operate in perfectly competitive input and output markets, where prices fluctuate independently of the decisions of any particular firm in the industry. Finally, real options seems to have gained more traction in companies where the majority of managers and other employees have science or engineering backgrounds, and are thus comfortable dealing with the basics of probability theory and quantitative modeling.

While the projects or situations in which real options analysis is most widely used have several common characteristics, there are many differentiating features among these applications. For instance, some projects involve a capacity decision, while others require a simple go/no go decision. In some cases, investment decisions may be contingent on one key source of uncertainty that resolves in a continuous fashion over time, while in other cases there may be several variables whose uncertainty is resolved only if the firm invests in information acquisition. Not surprisingly, many of the more recent studies of real options have focused on tailoring real options analysis to better suit applications according to the specific structure and unique characteristics of each type of investment decision. Such studies serve both to refine and to reinforce our intuitive sense of the effect of real options on the strategy, value, and risk of projects and companies in different industries.

Real Options in the Crosshairs

Despite the growing number of successful implementations, real options has its fair share of critics among practitioners. And as the profile of real options has increased in recent years, the critics have become both more numerous and more vocal. The criticisms aimed at real options seem to fall into four main categories.

First, real options has on occasion been identified as one of the causes of the Internet bubble—and it has even been blamed for the demise of Enron. Loose talk about growth options may well have been used to justify what we now know were sky-high valuations of certain technology-related firms, particularly early-stage Internet ventures. While this type of hot air may be capable of inflating a late-90s-style equity bubble, there were plenty of other plausible suspects, from aggressive accounting to media hype to the proliferation of inexperienced "day traders."

In the only published valuation model of an Internet company that I'm aware of, Eduardo Schwartz and Mark Moon developed a carefully calibrated real options analysis to value Amazon at the end of 1999. [8] The stock price they obtained was roughly one-sixth of Amazon's traded price at the close of 1999, and reasonably close to the post-crash stock price. Thus, while a real options "mindset" can be useful, there is no substitute for careful analysis.

As for Enron, it became one of the more prominent poster children for real options. The company had success-

8. Eduardo Schwartz and Mark Moon, "Rational Pricing of Internet Companies," *Financial Analysts Journal*, Volume 56 (May/June 2000).

fully implemented real options in various facets of its operations, at least from a tactical perspective. But, as has become clear, the demise of Enron had to do with many factors quite unrelated to the use of real options—and thus those critics of real options who point to Enron, or more generally to energy trading companies, appear to be throwing the baby out with the bathwater.

A very different type of critique comes from a separate camp, namely decision analysts, who question the originality and, in some cases, the appropriateness of real options analysis. After all, the idea of systematically mapping out a range of scenarios over time and analyzing how managers should react under these different scenarios was developed by decision analysts four decades ago. Furthermore, some real options analyses have been criticized as inappropriately bundling together "private" and "market" risks, thereby sacrificing some of the specific information that pertains to each of these types of uncertainties.[9]

There is clearly some merit to this "old wine, new bottles" critique. And there are undoubtedly circumstances where decision analysis represents a perfectly reasonable, and considerably more straightforward, approach. But having made that concession, I would argue that real options has at least four significant advantages over conventional decision analysis. First, it has focused attention on the objective of shareholder value maximization. Second, and related to the first point, to the extent that investors' value expectations, and their tradeoffs between risk and return, are reflected in equity and derivatives markets, information from these markets can be used to get more precise estimates of the value that would be created by projects under consideration *from the perspective of the firm's shareholders*. Third, the conceptual framework and shorthand vocabulary of options has helped to simplify the framing of investment decisions. Fourth, at least some decision analysts concede that real options has placed more emphasis than earlier frameworks on "downstream" decisions, such as decisions to abandon uneconomic projects or to expand projects that have become more promising with time.

Now I turn to what I believe are the two significant critiques of real options that both academics developing models and practitioners implementing these models should consider quite seriously. The first is that real options models tend to reflect "perfection" rather than economic reality. Managers are assumed to be completely rational and loyal to the firms' shareholders. They can be counted on to make the right decisions at exactly the right time. The right times to invest in options and to exercise them are in turn all based on managers having perfect information about the relevant parameters that determine the underlying project's value and volatility. On top of these assumptions, the execution of all projects is assumed to be completely unaffected by the firm's other projects, its capital structure, its hedging activities, or by the actions of other firms that may invest in and exercise similar options. While such assumptions clearly simplify the job of modeling investment decisions, they obviously fail to capture important realities of corporate decision-making.

The other—and to me the most formidable—objection to real options would appear to come from the opposite direction. That is, rather than criticizing the simplicity and artificiality of the models, many practitioners view the existing models as too complicated to use and even more so to explain. I call this the "Real Options as an Extreme Sport" critique. Although it may be impressive to see a real options analysis being performed with all its subtle maneuvers, this is not something that you would feel comfortable trying in your own business, let alone trying to explain to a corporate board of directors. Senior management is understandably leery of any black box presented to them by the champions of a project.

Bridging the Gap Between Theory and Practice

The last two critiques of real options by practitioners lead me to cite five key challenges that need to be addressed by future researchers so that our collective research efforts can achieve the goal of providing sound guidance to improve the practice of decision-making. The five main challenges are these: (1) refining the models of perfection; (2) splitting options; (3) modeling managerial behavior; (4) developing heuristics; and (5) valuing the whole firm.

Refining the Models of Perfection

As mentioned earlier, many of our existing models, and certainly the ones that have made their way into practice, reflect a set of assumptions based to a large extent on "perfect markets" and "value-maximizing managers." These models draw on the analogy between real options and financial options, without recognizing some of the key differences between them. For example, the underlying asset in most real options models is effectively (if not explicitly) assumed to be traded in liquid markets with a readily observable price. Option holders are assumed to exercise their options at the optimal time, and to ignore the actions of holders of identical options. Each option is treated as completely separable from other securities in the investor's portfolio. While these assumptions are fairly standard when dealing with financial options, they are clearly much less appropriate in the context of real options.

While we certainly need to address the fundamental differences between real options that are held as part of a corporate entity and financial options that are held within a portfolio of traded securities—and I will discuss some of these differences shortly—there are a number of important

9. See Adam Borison, "Real Options Analysis: Where Are the Emperor's Clothes?" in this issue.

ways in which real option valuation models can be further refined from a technical perspective. This line of research parallels in many ways the significant advances that have been made in the financial option pricing realm over the last couple of decades, and that continue to be pursued.

First, and I believe foremost, we need to be careful about specifying the distribution for each of the underlying assets in our model, whether that be a specific commodity price or demand, or a "bundled" uncertainty in the form of the underlying project value. In many of the applications in which real options analysis is used, the distributions of the uncertainties differ significantly from the standard lognormal distribution that is assumed in Black-Scholes and other related models. There may be mean-reversion or jumps in the process for the underlying variables, and the volatility and convenience yields may be stochastic. In the case where there is more than one uncertainty, the correlation may also be stochastic.

Models based on new distribution specifications will continue to be an important contribution to academic literature and to practice, as will research that provides better guidance on how to estimate the nature of the distribution and the key parameters involved. Since the distributions assumed will define the scenarios through time and the cash flows in each scenario, these distributions may have a very significant effect on the valuation of the investment opportunity and the decisions made over time. Given this first-order effect, this presents a very important focal point for future research.

The second main ingredient driving the valuation and exercise of real options is the specification of the price of risk or, more formally, the state-contingent prices assumed for cash flows received at different points in time and under different scenarios. We all recognize that properly reflecting the way in which investors discount a future cash flow stream for its risk is a big challenge. It is also no easy task to explain clearly what techniques we are using to accomplish this. Nonetheless, the proper treatment of risk from the shareholder's perspective is one of the key features of real options that we are extolling, so we can't ignore this important challenge.

In the very specific case where we value real options using a set of commodity futures prices—take petroleum futures, for instance—the risk-return relationship is implicitly embedded in the certainty-equivalent values that the futures prices represent. However, the maturity of these futures contracts typically stop far short of the horizon of the projects we are trying to value, creating challenges in accurately valuing the cash flows at the far end of the project's life. Furthermore, the petroleum-based project is unlikely to have the same liquidity as the package of futures contracts used to replicate the project, and this issue should be considered somehow in the valuation of the project.

For the majority of real options applications, relevant futures markets do not exist and thus futures prices can't be used. Instead, the price of risk that we need to account for in the valuation is effectively obtained by finding "comparable" investment opportunities in the market. This is the essence of the standard DCF procedure we have used in corporate finance for decades. The main difference in this regard between what we do in real options versus in a standard DCF calculation is that, rather than finding a comparable for the investment opportunity we are ultimately trying to value—the real option—we obtain a comparable for an underlying, or option-free, project. We do this because the risk profile of the underlying project is much more stable and straightforward, and thus we have a better chance of matching it with a comparable in the market.

But when we then go to the market to find comparable firms, we rarely find nice, clean, "pure-play" investments that resemble the option-free underlying project. Instead, we tend to find companies very much like the one whose real option we are trying to value—companies that consist of both cash-generating "assets-in-place" and less tangible future growth options. Another approach for a company valuing its real options is to use its own WACC to value the underlying project. The problem with this common practice, however, is that because the WACC presumably represents a blend of the expected rates of return on both lower-risk assets-in-place and higher-risk options, it is likely to overstate the risk of the underlying project.

The key point here is that we haven't yet provided consistent guidance on how to get clean estimates of discount rates for underlying projects and, thus, for most investment opportunities for which real options techniques are used—and so risk is not properly being accounted for. We need to work on this deficiency, which clearly limits the precision of valuations in practice.

The third way in which our models of perfection can be further refined is to develop superior computational methods to obtain accurate solutions in an efficient manner. One significant advance in this direction is the development of more flexible Monte Carlo simulation models that can be used to value American-style options. Since Monte Carlo simulation readily accommodates multiple uncertainties and complex distributions, its ability to handle problems with multiple decision points has created a powerful solution method that can be used with most real option problems that occur in practice.

Splitting Options

Turning away from our models of perfection, let's now consider the various features that make real options different from financial options. One of the key differences is that many real options, particularly growth options, are not held exclusively or completely by just one company.

Rather, the potential gains from these options are split across more than one party.[10] There are a couple of ways in which this happens.

The first, and the one that receives the most attention, stems from competition between two or more companies involved in the same type of business—for instance, technology companies that are planning to launch similar new products. There have been numerous models of competition developed in the real options literature, and this will continue to be one of the key research avenues in this area. The complexities of game theory are further complicated by the dynamic nature of real options problems. In addition to elegant models that allow us to derive interesting insights about corporate behavior in a context where companies compete to exercise similar growth options, we have extensive tree-based game theory/real options models that, while more cumbersome, are potentially more applicable in practice. Yet, there is significantly more to be done in this area, particularly since the results of game theory models are often quite sensitive to the underlying assumptions of the model.

The second way in which real options are split between parties is across the different links of a value chain. While some growth options may lie entirely within vertically integrated companies, most growth options in the economy are created and exercised by the cooperative activity of more than one firm. For instance, the option to expand capacity in the airline industry is split across the airlines and the aircraft manufacturers, not to mention airports and other entities. The manner in which options are split between parties is governed by the contractual agreements between those parties. The appropriate design of those contracts is critical to ensuring that the investment in, and exercise of, the overall growth options are done in an optimal fashion so that the options' values are maximized. The contract design, which involves remedies in the case of breach, and may itself involve option features, will determine whether the parties pursue their own conflicting objectives, such as investing at the wrong time or at too high or low a level, or instead work to maximize the value of the partnership.[11] Thus, providing guidance on how to design contracts is essential to extracting the full value of growth options and other real options that exist in the economy.

Government regulation may also determine how growth options are split in many industries, both horizontally across direct competitors and vertically across the value chain, including consumers. For instance, regulation of the power and energy industries, and broader anti-trust and patent regulation and enforcement, will affect how companies invest in and exercise their growth options, and thus should be carefully designed to promote efficient creation and exploitation of growth options.

Modeling Managerial Behavior

To borrow a well-known saying about guns, decision tools don't make decisions, people do. Unless we can appropriately understand managerial behavior, and either modify it or compensate for it through our decision-making tools, the decision support tools that we design may not necessarily yield the results we expect. The two key issues of managerial behavior that need to be addressed are unintended mistakes stemming from "cognitive biases" and intentional actions arising from misaligned incentives.

In virtually all corporate investment evaluation situations, even if there are some variables that can be accurately assessed from financial markets (such as the spot and futures prices of oil), other variables will need to be subjectively estimated (such as the expected volume of reserves). Of course, one of the lessons of real options is that we need to infuse rigor into the evaluation process, and that means attempting to make the estimates of our evaluation inputs as objective as possible. But it is widely recognized that the cognitive biases of managers, subject matter experts, and analysts tend to creep into the analysis, creating more or less predictable distortions.

It is difficult to ignore these and other cognitive biases of managers, since they can have a significant impact on the recommendations produced by a real options analysis. Moreover, a company's culture and its organizational structure may influence this behavior—for instance, by encouraging optimism as a generally positive managerial attribute. The emergent field of behavioral corporate finance has started to address some of these issues.[12]

While cognitive biases may lead to inadvertent inefficiencies in investment policy, the incentive structure that drives managerial behavior will have a more deliberate impact on managerial decision-making. Compensation systems that reward short-term earnings and cash flow, either directly or indirectly (say, by being tied to short-term stock performance) may discourage investment in early-stage options (such as R&D) that will consume cash, while encouraging premature exercise of later-stage growth options that will produce earnings and cash.[13]

Aside from near-term compensation, managers will also clearly consider the implications of their project choices on their careers. Managers' decisions to take on projects may be influenced more by the projects' expected effects on the size

10. See Peter Miller and Ted O'Leary, "Managing Operational Flexibility in Investment Decisions: The Case of Intel," *Journal of Applied Corporate Finance*, this issue.

11. Under the frequently used expectations damages remedy for breach, a growth option shared by two parties will be suboptimally exercised, and the loss in value can be quite significant; see A. Triantis and G. Triantis, "Timing Problems in Contract Breach Decisions," *Journal of Law and Economics*, Vol. 41 (1998).

12. See Hersh Shefrin, "Behavioral Corporate Finance," *Journal of Applied Corporate Finance*, Vol. 14, No. 3 (Fall 2001).

13. See John Graham, Campbell Harvey, and Shiva Rajgopal, "The Economic Implications of Corporate Financial Reporting," *Journal of Accounting and Economics* (2005).

of their business units, or on their future allocations of the corporate budget, than on their ability to generate shareholder value. For similar reasons, managers are also likely to prefer to stick with a losing project as long as possible (with the hope that things will improve) instead of exercising their abandonment option.

The cognitive bias and misaligned incentives of managers have two important implications for real options models. The first is that we need to incorporate actual managerial behavior into our models. While one could also make this comment in the context of standard capital budgeting techniques, it is much more relevant here. After all, the key underpinning of real options is the existence of managerial flexibility—and while this flexibility can be used to create value for shareholders, it can also be used by managers to benefit themselves at the expense of shareholders.[14]

The second key implication of the managerial behavior I have described is that we need to provide guidance on how to redesign compensation systems, organizational structures, and investment evaluation processes that account for managers' cognitive biases and their incentive-driven behavior, and that reflect the type of complex investment decisions that managers control over time. The ability to distinguish ex post between good outcomes and good decisions will always be a challenge, and managers will always try to rationalize bad outcomes and claim credit for good outcomes. Two promising ways to address these issues are indexing performance metrics to industry outcomes and delaying compensation to match the duration of projects, at the very least by lengthening the vesting period for equity-linked compensation.

Developing Heuristics

For the most part, academics focus on making models accurate rather than simple. However, theoretically accurate models are often poorly executed in practice *because of* their complexity, while simple models can often be quite effectively employed despite their lack of precision. In the end, it is not clear which is better. One could certainly argue that simpler real options models are more likely to be employed in practice, thus reducing the use of less accurate valuation models such as NPV and so resulting in better (though not optimal) decision-making. Yet relatively little is being done to develop better heuristics, or simpler approaches, to evaluate real options and their associated exercise strategies.

This does not imply that we shouldn't attempt to refine our already complex models in order to make them more theoretically sound. But in the end, those models may serve more as benchmarks to gauge the accuracy of simpler models rather than as the models that are ultimately used in practice. We can then carefully evaluate which heuristics seem to work best in different situations.

Consider three valuation heuristics that are now widely used in practice. The first, and by far most popular, is the NPV rule, which uses a company's WACC to discount expected earnings or cash flows. The NPV technique works quite well under some conditions—namely, if the project's risk is similar to that of the overall firm, if a constant leverage ratio will be maintained throughout the life of the project, and if there is little option value embedded in the project (either because the project is a now-or-never opportunity or there is little flexibility to alter the course of the project over time). But given the restrictiveness of these conditions, it is also clear that NPV will not work in many cases, and it is for these situations that we may need better heuristics.

Another heuristic involves a simple modification to the standard NPV rule—one that involves raising the discount rate above the firm's cost of capital. This has been proposed for situations where there is a valuable option to delay a project.[15] While this may not lead to the exact optimal exercise policy, the error is often small in terms of its impact on the value of the investment opportunity—and, perhaps surprisingly, the error does not appear to be all that sensitive to the gap between the assumed rate and the company's WACC. This heuristic is used in practice, perhaps not only as a way of accounting for the option to delay, but also as a crude means of offsetting excessively optimistic cash flow forecasts for projects.

Another frequently used class of NPV-based heuristics includes sensitivity, scenario, and simulation analyses. These types of analyses try to overcome one of the major shortcomings of standard NPV that real options analysis directly addresses—notably, the near-exclusive focus on average or most-likely values, with little attention to the potential distribution of outcomes. Sensitivity and simulation analyses help decision makers better understand the effect of the entire distributions of the different input variables on the value of a project. But unlike real options, these techniques fail to take account of managerial flexibility to respond to new information over time.

Scenario analysis, by contrast, lays out a few possible paths of future development, and then devotes considerable attention to exploring the ways that managers can respond to each. But, in addition to focusing on only a few possible outcomes, scenario analysis has two major shortcomings

14. It is in this line of research where empirical studies on real options could prove to be most useful. For instance, by observing corporate investment behavior and comparing it to our rational models of creating and exercising real options, we might be able to calibrate the degree of suboptimality of exercise decisions in practice. But this will clearly be extremely challenging, since it assumes that the researcher is able to estimate both the true parameters of the underlying valuation model as well as managers' estimates of those parameters. Only then would we be able to conclude whether the exercise decisions are being driven by managerial incentives that differ from those of shareholders, or whether management unknowingly misestimated the input parameters to the model.

15. See Robert McDonald, "Real Options and Rules of Thumb in Capital Budgeting," in M. J. Brennan and L. Trigeorgis, Eds., *Project Flexibility, Agency and Competition* (London: Oxford University Press, 2000).

vis-à-vis real options analysis. First, in scenario analysis, a decision taken at any particular point in time is based on the implicit assumption that only one particular path of uncertainty resolution will materialize in the future. In real options analysis, by contrast, *all* possible future paths are effectively considered when making the decision. Second, as with traditional decision tree analysis, scenario analysis does not do a good job of accounting for the effects of risk on the valuation of a project. Despite such limitations, however, scenario analysis is a useful supplement to standard NPV analysis and can lead to better decision-making.

Given the wide use of NPV and its variations, there is clearly a demand in practice for simple techniques that can address the impact of uncertainty and managerial flexibility when making capital investment decisions. If one objective of academic research is to provide practitioners with sound methods to use in practice, it is not enough for academics to simply generate complex analytic techniques and then allow practitioners to figure out how to simplify them for implementation. Rather, academics should formally evaluate different heuristics to figure out which ones are reasonably accurate, and which have the greatest potential to mislead management in their investment or strategic evaluation process. We need to better understand which complexities in real option models are necessary for specific applications, and which add little in the way of accuracy while detracting from the transparency of the valuation methodology. If management finds real options analysis to be too complex a tool, or suspects that the tool can be deliberately or unintentionally misused in ways that are difficult to detect, it simply won't be used—and the gains we expect from the better framing and evaluation of projects will not be realized.

Finally, an important ingredient in enabling the technology transfer from ivory towers to corporate headquarters is the development of software that facilitates the framing of the decision problem, the computations involved in the solution process, and, critically important, the presentation of results. User-friendly software will undoubtedly help to promote the use of real options in organizations. There are already several software packages in use and in development. Some are based primarily on decision tree or binomial lattice frameworks, while others employ simulation as the underlying modeling technique, which works particularly well for investment situations where there is a single decision point. I expect that we will see much more software design activity in the near future.

Valuing and Managing the Firm

Corporate executives are very responsive to the ways in which their companies are evaluated by their investors and by the financial intermediaries who supply information to investors. If EPS is the key metric followed by analysts, managers will focus on ensuring stable growth in EPS, even if this results in decisions that reduce the fundamental long-term value of the company. Thus, in order for more companies to focus on enhancing the value of their real options, and thus on evaluating their options accurately, more analysts and sophisticated investors will need to adopt real option analysis as at least one of the tools they use for assessing shareholder value. But this unfortunately appears a long way off.

To get to that point, the previous four research agenda items need to be addressed, especially the development of simpler models. But there are other issues as well that need to be considered in determining the overall valuation of a company. For instance, how do the various projects or options to invest within the company's portfolio interact with each other? The exercise of each growth option in a company may affect the value of the company's current assets and its other growth options, and thus the incremental value of each growth option is difficult to assess accurately. Another important challenge is to capture the effect of a company's financing and risk management strategies on the exercise and value of the firm's options. Since a company's financing policy, like its investment strategy, is likely to be dynamic rather than static, it is challenging to value the tax shields associated with the company's portfolio of current and future investment. Furthermore, to the extent that external financing is needed to exercise the firm's growth options, the costs and constraints associated with external financing will affect the value of the firm's options.

Given the complexity of the task, it is not surprising that real options analysis hasn't yet hit its stride as a leading method for corporate valuation. Part of the problem, of course, is the difficulty in obtaining the type of detailed information required to perform an accurate valuation analysis. However, more analysts now appreciate the importance of viewing companies as portfolios that must be disaggregated to be valued properly. There is also growing awareness of the shortcomings of standard DCF analyses that rely on most-likely scenarios rather than accounting for the full range of possible scenarios for a company's future. Thus, real options has already piqued the interest of many analysts who are looking for better valuation techniques.

As interest in the analyst community grows, it seems inevitable that companies will increasingly adopt a real options-based framework for looking at corporate decisions in which uncertainty and managerial flexibility are key considerations. Companies will revisit not only how they allocate capital, but also how they should structure dynamic financing and risk management policies, and how they should design incentive compensation systems so that managers are more likely to carry out the optimal policies.

Going Forward

Real options provides an important opportunity to improve the science of valuation and the practice of management.

Nevertheless, there is—and will always be—much that is art rather than science in this process. Organizations don't adapt very readily to applying any new tool, particularly one as sophisticated as real options. Corporate acceptance and implementation will require senior-level buy-in and strong leadership, careful adoption of simpler versions of the tool, user-friendly software that can handle the modeling complexity, significant investment in training analysts and managers, deliberate alignment of managerial and shareholder incentives, and the creation of appropriate controls in the capital investment process. Despite these challenges, I believe that there will continue to be a gradual and consistent diffusion of real options analysis throughout business organizations over the next few decades, and that real options will eventually become a standard part of corporate strategic planning and the valuation of capital investment projects. When this happens, NPV will assume its rightful role as a special case of capital investment decision-making, as will other special cases to be used for particular applications—and real options will no longer be considered a "supplementary" capital budgeting tool.

But it would be naïve to think that there will not continue to be a lot of resistance. Academics must listen carefully to the critiques of practitioners and allow them to influence the kinds of problems that are addressed in academic research. To the extent that we can be responsive to the concerns of practitioners, and improve the normative models we offer them, real options will have the type of profound impact that we have long been expecting, but which has not yet been realized.

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Journal of Applied Corporate Finance (ISSN 1078-1196 [print], ISSN 1745-6622 [online]) is published quarterly on behalf of Morgan Stanley by Blackwell Publishing, with offices at 350 Main Street, Malden, MA 02148, USA, and PO Box 1354, 9600 Garsington Road, Oxford OX4 2XG, UK. Call US: (800) 835-6770, UK: +44 1865 778315; fax US: (781) 388-8232, UK: +44 1865 471775.

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