

Real Options: Taking Stock and Looking Ahead

Yong Li

*State University of New York at Buffalo, School of
Management*

Barclay James

*University of Illinois at Urbana–Champaign, College
of Business*

Ravi Madhavan

*University of Pittsburgh, Katz Graduate School of
Business*

Joseph T. Mahoney

*University of Illinois at Urbana–Champaign, College
of Business*

Abstract

We discuss recent developments in real options theory and its applications to strategic management research, examine the potential difficulties in implementing real options in theory and practice, and propose several areas for future research. Our review shows that real options theory has provided important insights into investment and exit decisions as well as into the choice of investment modes. In addition, extant research studies have contributed substantially to our understanding of whether and how organizations can benefit from real options. Future research that addresses difficulties in applications will further advance both real options theory and practice in strategic management.

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Yong Li

School of Management
State University of New York at Buffalo
326B Jacobs Management Center
Amherst, NY 14260
Phone: (716) 645 2522
Email: YL67@buffalo.edu

Barclay E. James

College of Business
University of Illinois at Urbana-Champaign
350A Wohlers Hall
1206 South Sixth Street
Champaign, IL 61820
Phone: (217) 333-2420
E-mail: bejames@uiuc.edu

Ravi Madhavan

Katz Graduate School of Business
236 Mervis Hall
University of Pittsburgh
Pittsburgh, PA 15260
Phone: (412) 648-1530
Email: rmadhavan@katz.pitt.edu

Joseph T. Mahoney

College of Business
University of Illinois at Urbana-Champaign
140C Wohlers Hall
1206 South Sixth Street
Champaign, IL 61820
Phone: (217) 244-8257
E-Mail: josephm@uiuc.edu

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ABSTRACT

We discuss recent developments in real options theory and its applications to strategic management research, examine the potential difficulties in implementing real options in theory and practice, and propose several areas for future research. Our review shows that real options theory has provided substantial insights into investment and exit decisions as well as into the choice of investment modes. In addition, extant research studies have contributed significantly to our understanding of whether and how organizations can benefit from real options. Future research that addresses difficulties in applications will further advance both real options theory and practice in strategic management. We call for future generations of research to enhance the impact of real options as an emerging dominant conceptual lens in strategic management.

Key words: Real options, uncertainty, investment decisions, governance, and performance.

INTRODUCTION

Summarizing the influential theories that form the economic foundations of strategic management as (1) the behavioral theory of the firm; (2) transaction costs theory; (3) property rights theory; (4) agency theory, and (5) dynamic resource-based theory, Mahoney (2005) has identified real options theory as an emerging dominant conceptual lens for strategy. This study takes stock of some key research conclusions in this area and offers recommendations for the next generation of research in the evolving science of strategy and organization.

Real options theory has had increasing influence in strategic thinking since the seminal works of nearly three decades ago (Kester 1984; Myers 1977; Myers 1984). Two broad streams of research have emerged since the 1990s, relating to two core strategy topics: investment decisions and their economic performance implications. The first stream has investigated investment and divestment decisions as well as investment mode choices. The second stream has focused on the organizational performance implications of real options investments. Taken together, these research studies contribute to the core concern of strategic management with firms' strategic choices and their economic performance (Rumelt, Schendel, and Teece 1994). Real options theory has made unique contributions in these two research streams by providing a theoretical explanation for why firms may make investment decisions that differ from what the net present value (NPV) approach would prescribe, as well as by proposing that, under certain conditions, real options value will comprise a substantial portion of the economic value of projects, lines of business, and firms.

More recent works from a real options lens have also reached out to consider issues such as agency and economic incentive problems (Arya, Glover, and Routledge 2002), transaction

costs (Chi and McGuire 1996), resources, capabilities and learning (Bernardo and Chowdhry 2002; Childs and Triantis 1999; Vassolo, Anand, and Folta 2004), and game-theoretic aspects of investment (Grenadier 2000; Smit and Ankum 1993; Smit and Trigeorgis 2004; Trigeorgis 1991). These extensions of real options build on critical differences between financial options and real options. For example, real options are created and exercised at the discretion of managers, and managerial decisions may be subject to agency and transaction costs problems. Similarly, managerial decisions are enabled and constrained by the resources and capabilities available to the organization, and learning occurs in a sequential investment process as well as across investment projects. Finally, real options may not be proprietary but shared, and their economic value will be affected by industry structure, competitive interactions and a firm's market position. By incorporating these various strategic issues into a real options framework, recent research studies have not only enriched real options theory but also brought this emerging theory closer to the heart of strategic management.

We divide our review into two parts. The first part 'takes stock' of the extant real options literature with a focus on its applications in the area of strategic management. The second part examines some critical issues in theoretical and empirical research, including issues in implementing real options in theory and practice. This part also looks ahead at potential areas for future real options research in strategic management. Figure 1 provides a roadmap of the key sections and major takeaways.

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TAKING STOCK: APPLICATIONS OF REAL OPTIONS THEORY

IN STRATEGIC MANAGEMENT RESEARCH

‘Taking Stock’ has three sections. Section 1 examines investment decisions, an area of real options theory that has received a substantial amount of attention. Section 2 discusses how real options theory contributes to our understanding of investment mode choices, an especially relevant area to strategic management and organizational economics. In Section 3, we present an overview on the performance implications of real options investments to organizations. Table 1 provides a summary of the identified themes and the key research studies that represent the application of those themes to the core concerns of strategy and organization.

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Investment and Divestment

This section first considers the implications of common real options for investment decisions. These real options include the option to wait-to-invest (or the option to defer), the options to abandon and switch, and corporate growth options. Next, we look at recent extensions of real options theory of investment by considering options portfolios, competitive dynamics, and endogenous uncertainty and learning. Finally, we discuss exit decisions and entry/ exit delays or hysteresis.

Common real options and investment decisions

Companies make capital investments in order to create and take advantage of profitable opportunities. These opportunities are real options – rights but not obligations to take some action in the future. In this sense, real options are akin to financial options. A simple financial

option gives its holder the right, but not the obligation, to buy or sell a specified quantity of an underlying asset at a specified price (i.e., the exercise price) at or before a specified date (i.e., the expiration date). By analogy, a real option confers on the firm the right, but not the obligation, to take some action in the future. The option is 'real' because the underlying assets are usually physical and human assets rather than financial securities. The commonality in applying option-pricing models for real assets and for financial securities is that 'the future is uncertain (if it were not, there would be no need to create options because we know now what we will do later) and in an uncertain environment, having the flexibility to decide what to do after some of that uncertainty is resolved definitely has value' (Merton 1998: 339). Although the term 'real option' is used with multiple meanings in financial economics and management, a key feature is that the real option creates economic value by generating future decision rights (McGrath, Ferrier, and Mendelow 2004), or more specifically, by offering management the flexibility to act upon new information such that the upside economic potential is retained while the downside losses are contained (Trigeorgis 1996). Capital investments are essentially about real options (Dixit and Pindyck 1995). Traditional investment theory holds that investments should be made when the simple NPV of an investment opportunity equals or exceeds zero and assumes that the investment must be made either now or never. Such an investment approach, however, fails to consider that management can adapt and revise its strategies in response to unexpected market and technological developments that cause cash flows to deviate from their original expectations. The traditional approach thus ignores the possibility that capital investments can be started at some other time.

Option to wait-to-invest. Real options theory provides a sound theoretical basis for considering why firms may not invest according to the traditional investment theory. In a world

of uncertainty, when investments are typically irreversible, the real option to invest can be more economically valuable than immediate investment or delayed commitment because this option offers management the strategic flexibility to defer undertaking the investment until receiving additional information. The firm may decide to invest when market conditions turn favorable or to back out if market conditions are adverse. On the other hand, if the firm decides to invest immediately, the firm forgoes the option of investing in the future when more information has been revealed. The lost option value of waiting or deferral is an opportunity cost that must be included as part of the economic cost of the investment project. Thus, the real option to invest should not be exercised as soon as it is 'in the money,' even if doing so has a positive NPV. Instead, the present value of the expected cash inflows from a project must exceed the cost of the project by an amount equal to the economic value of keeping the investment option open (Dixit 1989; McDonald and Siegel 1986).

Since the value of the option to wait-to-invest increases with exogenous uncertainty that is reducible with the passage of time, a strategic implication of real options theory is that investment will be discouraged by exogenous uncertainty. A number of research studies have examined the relationship between investment and uncertainty at the firm level of analysis (cf. Carruth, Dickerson, and Henley 2000). For a sample of Italian manufacturing firms, Guiso and Parigi (1999) find that holding the level of demand constant, increasing uncertainty from its sample mean to the 95th percentile lowers firm-level planned investment scale by 15.3%. Campa (1993) similarly observes a negative relationship between exchange rate volatility and the number of foreign entries in the US market. Folta and Miller (2002) find that firms acquire additional equity stakes from their partners when the biotechnology subfield of the partners has lower uncertainty.

Real world investments are typically multi-stage and involve not only the initial option to wait-to-invest, but also the future possibilities of growth and abandonment once an investment is initiated. Assuming costless ability to wait would disregard future growth options, while assuming complete irreversibility would eliminate the put option of abandonment (Dixit and Pindyck 2000). The options of abandonment, switching and growth are discussed below.

Options to abandon and switch. The simple NPV rule in corporate finance anticipates no contingency for abandoning an investment project or switching inputs and outputs if market conditions turn out to be worse than expected. When a firm purchases an asset that the firm may later resell or put to an alternative use, the firm acquires a put option, namely the capability to abandon or switch should future conditions be sufficiently adverse. As compared with the conventional financial analysis of economic salvage or exit value, real options theory proposes that the strategic value of the put option (via abandonment or switching) increases with the salvage value and future uncertainty (Berger, Ofek, and Swary 1996; Myers and Majd 1990).

Availability and recognition of this put option will increase a firm's propensity to invest relative to what would be suggested by a simple NPV rule, which assumes that the investment project continues for its physical lifetime and omits the possibility of future divestment (Dixit and Pindyck 1995). This positive effect of the abandonment/ switching option on investment propensity is particularly important to investment decisions concerning multi-stage projects (Chi and Nystrom 1995; Schwartz, 2003). Given that abandonment before completion saves a portion of the total investment cost, the expected cost to be incurred with some stages still remaining must necessarily be lower than the total investment cost if there exists a positive possibility for the project to be abandoned before completion. Hence with the option to abandon the project in adverse market developments, the threshold value for the optimal decision rule is in general

smaller than the full incremental costs.

When investments can be *fully* recovered or *costlessly* redeployed (should market conditions turn worse than anticipated), firms can invest and divest at their will because the downside economic loss is completely contained. However, because real assets are typically firm-specific, industry-specific, or subject to market imperfections, real assets are *irreversible* to various degrees (Dixit and Pindyck 1994; Rivoli and Salorio 1996). As irreversibility increases, exit value decreases and the option value of abandonment is reduced. Next, we consider corporate growth options and investment decisions.

Growth options. Real investments are often made not only for immediate cash flows from the project but (perhaps primarily) for the economic value derived from subsequent investment opportunities. Such future discretionary investment opportunities are growth options (Kester 1984; Pindyck 1988; Trigeorgis 1988). For example, firms usually undertake R&D investments to strategically position themselves for the economic value from commercialization when market conditions turn favorable (McGrath 1997). Similarly, firms usually make foothold investments in a new foreign market for the possibility of expansion in the future (Chang 1995; Kogut 1983). Such growth-oriented investment may appear uneconomical when viewed in isolation but may enable firms to capture future growth opportunities.

Multi-stage projects are prototypical cases of investments involving corporate growth options. Multi-stage investment opportunities can be analyzed as simple call options. First-stage investments are undertaken to *create* growth options whereas second-stage investments are made to *exercise* growth options. In technology development, for example, first-stage R&D expenditures are the price paid for subsequent growth options, the costs of second-stage commercialization are exercise prices, and the economic value of technology options are the

underlying claims to commercialization (McGrath 1997). Such multi-stage investment opportunities can also be analyzed as compound options. In the case of technology development, initiating R&D in an area can be viewed as exercising the initial option to invest, which in turn leads to the creation of other real options, such as the option to commercialize or the options to abandon and switch. Concerning investment decisions, the advantage of viewing growth options as simple call options is that simple options are more prone to analysis, while conceptualizing multi-stage investment opportunities as compound options has the advantage of explicitly considering the abandonment and switching options that are typically important in multi-stage projects (Schwartz, 2003).

Research studies have empirically examined whether unexpected growth potential, indicative of growth options value, has the expected positive effect on investment decisions. Kogut (1991) proposes that when a firm initiates an alliance or an equity joint venture, the firm obtains an option to expand or acquire in response to future technological and market developments while retaining the option to defer complete commitment. Kogut (1991) finds that unexpected growth in the product market does increase the likelihood of joint venture acquisitions. Similarly, Folta and Miller (2002) show that managers acquire additional equity stakes of biotechnology partner when the subfield of the partner has larger growth potential. McGrath and Nerkar (2004) examine firms' motivations to invest in a new patent in a technological area and view patenting in the pharmaceutical industry as creating real options because a patent confers on the owner the right but not the obligation to make further investments for commercialization. McGrath and Nerkar (2004) find that the scope of the growth opportunity, as represented by the number of patent claims and the number of technological classes into which a patent is categorized, has a positive effect on a firm's propensity to take out

a new patent.

Options interactions. While the economic value of an investment project always increases with the introduction of additional options, the incremental value of each additional option is usually not equal to its economic value in isolation (Trigeorgis 1993). Specifically, the incremental contribution of each additional option to project value can be attenuated by ‘substitute’ options and/or enhanced by ‘complementary’ options (Kulatilaka 1995). For example, the option to wait-to-invest and the option to temporarily shut down are ‘substitute’ options. By making an investment, the firm reduces its strategic flexibility (to optimally time the investment later) so that in adverse future states of the world it would incur economic losses. The presence of the option to temporarily shut down has the effect of truncating the downside of the distribution of future cash flows, thus reducing the value of the wait-to-invest option. On the other hand, the option to expand and the option to temporarily shut down are ‘complementary’ options. The (temporary) shutdown option allows the firm to limit economic losses by temporarily shutting down during loss-making periods, while allowing the firm to take advantage of the upside potential by starting up when conditions improve.

Wait-to-invest options and growth options are often ‘dueling’ options in terms of their effects on investment decisions (Folta and O'Brien 2004). Waiting in the presence of growth options incurs opportunity costs. Therefore, whether a firm should undertake an investment immediately to take better advantage of growth opportunities, or defer the investment until the business environment is less uncertain, depends on the relative value of these two real options, which both increase with uncertainty.

When strategic investment has a substantial preemptive effect, it may bring the investor strategic advantages such as lower costs and higher market share (Kulatilaka and Perotti 1998).

As a result, even though the value of not investing increases with rising uncertainty, the value of the growth option may increase even more. On the other hand, when the investment confers only a modest strategic advantage, the potential profit gain may be less significant relative to the cost of the investment; an increase in volatility will increase the value of not investing and thus raise the threshold for investment in the growth option. Since maximum losses are bounded by the initial investment whereas the upside economic potential can be enhanced through strategic (first mover) advantages, at extremely high levels of uncertainty a further increase may favor strategic investment. Therefore, Kulatilaka and Perotti (1998) propose a *non-monotonic* effect of uncertainty on investment in the presence of strategic growth.

In a subsequent study, Lin and Kulatilaka (2007) focus on a situation where network effects are critical for gaining strategic advantages. Specifically, early investments in certain industries may shape the expectations of potential users and induce them to adopt a particular industry standard, thus creating a strategic growth option. Lin and Kulatilaka (2007) find through simulation that at high levels of uncertainty, the strategic growth option often dominates the waiting-to-invest option and reduces the investment threshold.

These theoretical predictions about a more complicated relationship between uncertainty and investment have attracted several studies in management. Campa (1993) finds that the effect of exchange rate volatility on foreign entry into wholesale markets is negative and remains monotonic. Using Compustat data with greater cross-sectional differences in growth potential, Folta and O'Brien (2004) find that the effect of uncertainty on industry entry is largely negative but turns positive with high strategic growth.

Real options theory also predicts a negative interaction between the prior option to invest and the subsequent abandonment option on investment decisions. The presence of the

abandonment option has the effect of truncating the downside of the distribution of future cash flows, and thereby reduces the economic value of the wait-to-invest options. Thus, the firm with valuable abandonment/ switching options will have greater tendency to invest than if the firm only considers the wait-to-invest option under uncertainty.

Since irreversibility reduces the value of abandonment options, an empirical implication is that irreversibility will likely strengthen the discouraging effects of uncertainty on investment propensity. For example, Campa (1993) finds that the higher the sunk costs (in terms of average ratio of fixed assets to net worth for firms in an industry), the larger the negative effect of exchange rate volatility on the number of foreign entries in the US. Guiso and Parigi (1999) observe that the negative effect of uncertainty is especially evident when accompanied by greater irreversibility in terms of asset liquidity in the secondhand market. Folta, Johnson and O'Brien (2006) conclude that the negative effect of uncertainty on market entry is more pronounced for industries with greater irreversibility as reflected by a larger required scale of entry, lower expected salvage value and more intangible assets.

Extensions of real options theory of investment

Recent research studies have extended the arguments of real options theory in many directions. In this study, we focus on portfolio of options, competitive dynamics and learning under endogenous uncertainty, topics that are particularly relevant to strategic management.

Portfolio of options. Firms usually undertake multiple projects and firms' strategic decisions can be viewed as bundles of resource-investment alternatives or real options (Bowman and Hurry 1993). Merton (1973) has suggested that it is more economically valuable to hold a portfolio of options than to hold an option on an asset portfolio assuming that the options being compared have identical terms and relate to the same underlying assets. A firm will usually have

greater strategic flexibility (i.e., access to more choices to maximize gains and/or minimize losses) by holding options separately. It is thus critical to allocate appropriate and sufficient resources to manage a portfolio of real options at the corporate level. By viewing R&D as creating real options, MacMillan and McGrath (2002) discuss how to manage the corporate R&D project portfolio as a portfolio of options. MacMillan and McGrath (2002) suggest that firms may align their strategy with available resources by grouping R&D projects into categories of real options depending on the nature and magnitude of technical and demand uncertainties.

Research studies have also analyzed how options portfolios affect firms' alliance and patenting activities. Vassolo, Anand and Folta (2004) view pharmaceutical alliances as exploratory investments in real options and propose that when strategic options are mutually competitive and correlated, the economic value of the options portfolio is sub-additive. They offer evidence that an alliance is more likely to be divested when it is more highly correlated with the rest of a firm's exploration activities in terms of low technological distance between the focal alliance and the portfolio of other alliances. In addition, Vassolo, Anand and Folta (2004) hold that when a firm possesses resources with public good properties that can be potentially leveraged in multiple settings, the economic value of the options portfolio is super-additive. McGrath and Nerkar (2004) examine the portfolio effect on patenting propensity and propose that due to decreasing returns of each additional option to firm value as well as the necessity to nurture and exercise existing options, firms already holding a portfolio of opened options are less likely to create new ones.

Competition and investment. When considering an investment decision, a firm is engaged in a game not only against nature (e.g., exogenous environmental uncertainty), but also against rivals. Competition complicates investment decisions. A firm may have to consider its

market position, the industry structure, competitive dynamics, and the nature of real options involved (i.e., shared or proprietary¹) (Kester 1984; Smit and Ankum 1993). It will also have to weigh between commitment value from preemption or early mover advantages and flexibility value from real options in investment projects (Smit and Trigeorgis 2004; Trigeorgis 1996). For example, Smit and Ankum (1993) suggest that while it is generally beneficial to postpone investment under uncertainty, waiting in perfect competition implies a loss in the expected value of the project due to anticipated competitive entry and such loss increases with the project value. In a monopoly, the dominant firm that possesses exclusive investment opportunities will incur no loss in value to competition during waiting. Therefore, there is a stronger tendency under monopoly to defer investment than under perfect competition, unless the project has a high expected NPV. Under oligopoly/ duopoly, firms tend to defer investing in projects with low NPV and uncertain market demand, provided that they can coordinate.

Suppose there is a two-stage investment project. A firm will have to decide whether and when to make the first-stage and second-stage investments. Unlike the wait-to-invest option, growth options usually have to be created through discretionary investments (Kogut and Kulatilaka 1994b). Therefore, in a sequential investment process, the first-stage investments can be thought of as creation of growth options whereas the second-stage investments as exercise of growth options.

Concerning second-stage investments or exercise of growth options, Kester (1984) suggests that a firm tends to exercise its growth option early if industry rivalry is intense or the growth option is shared among competitors. A timely commitment may preempt competitive entry or prevent erosion of the project value. On the other hand, a firm may defer exercising a

¹ Unlike financial options, real options are often shared. Proprietary real options provide *exclusive* rights of exercise while shared options are ‘collective’ opportunities of a number of competing firms or of a whole industry, and can be exercised by any one of their collective owners (Trigeorgis 1988).

proprietary growth option until more information is revealed without loss of the project value to competition. It is also suggested that uncertainty will likely have a stronger discouraging effect on investment incentives when firms have greater market power, possess proprietary options, or face less intense competition (Guiso and Parigi 1999). Assuming that buyout options are less proprietary with a larger number of equity partners, Folta and Miller (2002) find empirically that while the number of equity partners has an overall negative effect on acquiring additional equity, there is also a positive interaction effect between the number of equity partners and uncertainty on acquiring additional equity, suggesting that less proprietary options are exercised at a faster rate in the presence of high uncertainty.

Concerning first-stage investments, the investment decision depends on the focal firm's market position and the nature of competitive dynamics, among other factors (Smit and Trigeorgis 2004). When *preemption* of competitive entry in the second-stage is possible and strategic (first mover) advantages can be generated and sustained, the economic incentive to exercise the first-stage option to invest will be intensified despite uncertainty (Kulatilaka and Perotti 1998). However, even if resulting in a strategic advantage, an early investment may hurt competitors, and competitors may choose to respond aggressively, which may even lead to a price war. If so, the firm will be better off deciding not to invest. Similarly, if the focal firm cannot preempt competitive entry or obtain an exclusive right to subsequent growth options, and if competitors would respond aggressively, the firm should follow a wait-and-see strategy for its first-stage investment (Smit and Trigeorgis 2004). By delaying the first-stage investment, the firm prevents its rivals from growing at its own expense. Finally, when the firm's first-stage investment would benefit both the firm and its competitors in the subsequent stages, but competitors would reciprocate with an accommodating position (e.g., by maintaining high

prices initiated by the firm), the firm may adopt a committing but inoffensive strategy (Smit and Trigeorgis 2004).

By viewing patenting as creating options, McGrath and Nerkar (2004) maintain that because knowledge development is a cumulative process, competitive entry into an area is not only a market signal of its economic attractiveness, but actually makes the arena of the underlying technology more economically valuable by increasing the total investment in knowledge creation and uncertainty reduction. Consequently, McGrath and Nerkar (2004) observe a positive effect of competitive entry in a new technical area on a firm's propensity to take out a new patent.

In summary, an integrated real options and game-theoretic perspective suggests that the economic value of strategic growth options depends not only on industry growth potential but also on the "proprietaryness" of growth options and the persistence of strategic advantages. When a firm can obtain proprietary growth options or preempt competitive entry through the first-stage investment, the firm has a greater tendency to invest early even when investment returns are uncertain. The discouraging effects of uncertainty on investment incentives will be further reduced by the presence of strategic growth options. On the other hand, expected aggressive competitive responses will increase the likelihood that the firm is better off to adopt a wait-and-see strategy for projects with uncertain returns.

Endogenous uncertainty and learning. Uncertainty may be exogenous or endogenous to organizational actions (Pindyck 1993; Weitzman, Newey, and Rabin 1981). Whereas exogenous uncertainty is resolved with the passage of time, endogenous uncertainty can be substantially reduced through strategic investments. In this respect, our discussion so far has focused on managerial flexibility to adapt to changes in the environment, but management can

also invest to reduce endogenous uncertainty and influence the environment to its favor (Sanchez 1993; Sanchez and Mahoney 1996).

While both types of uncertainty increase the economic value of real options, they create opposing pressures on investment decisions. Exogenous uncertainty suggests the desirability of waiting for uncertainty to be resolved prior to committing to an investment. Endogenous uncertainty implies opportunities for learning, and as such, may actually encourage firms to invest (Weitzman *et al.* 1981). Roberts and Weitzman (1981) show that in sequential investments when the process of investing reduces both the expected cost of completion and the variance of that cost, and when the project can be stopped in mid-stream, it may be worthwhile to invest in the early stages of the project even though *ex ante* the NPV of the project is negative. Smit and Trigeorgis (2004) also show that learning generally triggers earlier investment by reducing future production costs, thereby eroding the economic value of the wait-to-invest option.

Pindyck (1993) discusses in detail the implications for investment decisions of two types of cost uncertainty for projects (e.g., a nuclear power plant) that take time to complete. The first type of cost uncertainty is technical uncertainty, i.e., uncertainty over the physical difficulty of completing a project, such as how much time, effort, and materials will ultimately be required for completing the project. Such uncertainty is only resolved as the investment proceeds but is largely diversifiable. The second type of cost uncertainty is input cost uncertainty, i.e., uncertainty over the prices of construction inputs or over government regulations affecting construction costs. Such uncertainty is external to the firm and may be partly non-diversifiable. Pindyck (1993) shows that both technical and input cost uncertainties increase the value of an investment opportunity. However, they affect the investment decision differently. Technical uncertainty makes investing more attractive, since investing reveals information about cost and

there is no value to waiting when information about cost arrives only when investment is taking place. Input cost uncertainty, however, depresses the incentive to invest now, because costs of construction inputs change whether or not investment is taking place, and there is a value of waiting for new information before committing resources. With regard to reduction of endogenous uncertainty through organizational actions, McGrath (1997) suggests that each firm has its own uncertainty profile in technology development and commercialization, and that firms can make pre-amplifying investments to influence uncertainty to their advantage and to enhance the economic value or the appropriability of the value of technology options.

Exit decisions and hysteresis

Real options theory has strategic implications not only for investing decisions but also for divesting decisions. Indeed, keeping options open under uncertainty applies to both investment and exit decisions. In traditional investment theory, if a firm does not exit the market at the point where the NPV becomes negative, the firm is behaving irrationally. Real options theory suggests that apart from psychological biases, exit delays may be a rational reaction to uncertainty and irreversibility.

Intuitively, the option of waiting to exit, even under non-profitable circumstances, has value because there is a possibility that market conditions turn favorable in the future to justify continuing the project now. This tendency for exit delays under uncertainty will be intensified by the costs of restarting the investment once it is temporarily stopped. Such restarting costs increase with irreversible sunk cost investments that will be lost with suspension but re-incurred for restarting. Therefore, the firm tends to keep the abandonment option open and delay exiting irreversible investments. Kogut and Kulatilaka (2001) suggest that the costs of altering tightly coupled components of technology and organization can be a source of irreversibility that tends

to encourage firms to persist in their old ways beyond the recommendation of the NPV rule. When organizational change is disruptive and hence discontinuous, managers hesitate to radically change their organizations, hoping perhaps that future states of the world will provide more appealing environments. Thus, inertia is rationally encouraged in highly volatile environments if change is costly (Kogut and Kulatilaka 2001). Chi and Nystrom (1995) suggest another rational explanation for exit delay under uncertainty: greater endogenous uncertainty such as that over the behavioral tendencies of cooperation partners implies higher learning potential through cooperation and firms will likely continue the current course of action until the costs of such learning outweigh the benefits.

In general, investment may not occur until profits exceed costs by the economic value of the option to invest; similarly, investment may continue until economic losses exceed the value of the option to continue derived from profitable operations in future good states of the world. Therefore, real options theory provides a rational explanation for economic ‘hysteresis’ (Baldwin 1988; Dixit 1992): When the underlying causes are fully reversed (e.g., profits fall below variable costs now), investment decisions may fail to reverse themselves (e.g., the firm may decide to continue the project). Between the level of economic profits that triggers investment and the level of economic losses that triggers exit, there is a ‘zone of inaction’ or a range of ‘optimal inertia’ in which a firm will maintain its status quo. For example, U.S. imports responded very slowly to the appreciation of the dollar in the early 1980s and even more slowly to the subsequent dollar depreciation to the 1980-level. Real options theory suggests that this ‘zone of inaction’ widens with increases in uncertainty and irreversibility (Dixit 1992).

Bragger, *et al.* (1998) have conducted several experiments to test real options predictions about exit delays, and find that in a computer simulated marketing scenario, experiment

participants receiving feedback higher in variability delayed exit decisions longer and invested more often than participants receiving feedback lower in variability. Moreover, since information becomes more valuable under uncertainty, participants with no opportunity to purchase information delayed exit decisions longer and invested more often than participants with the opportunity to purchase information.

These empirical results seem to be also consistent with the escalation of commitment theory. Bragger and colleagues (Bragger *et al.* 1998; Bragger, Hantula, Bragger, Kirnan, and Kutcher 2003) note that much research on escalation of commitment in social and organizational psychology has been conducted in an attempt to determine why individuals violate rationality and make ‘erroneous’ decisions to increase investment under failure (Staw 1981; Staw and Ross 1989). Escalation of commitment is more likely to occur when decision makers have received more equivocal feedback. Real options theory focuses more on inaction or continued investment by organizations under unprofitable conditions rather than on individuals’ escalated commitment under failure.

Organization and governance

Real options theory maintains that the managerial flexibility to adjust a predetermined course of action upon arrival of new information is economically valuable under uncertainty. We have so far discussed the implications of real options theory for whether and when to invest or exit. In many cases, the alternative courses of action are not just investing vs. waiting (i.e., not investing now) but rather how to invest or organize activities. Common investment modes (and governance structures) include collaboration (e.g., alliances and joint ventures), acquisition, and market transaction. Recent real options studies have provided additional insights into how investment activities should be organized. In this section, we first discuss real options studies on

the choice of investment modes, and then review research studies on option rights in collaboration contracts.

Choice of investment modes

How firms organize and govern their economic activities remains a central issue to the theory of the firm and its boundaries. Real options studies propose that the embedding of strategic options in a particular mode of governance can alter a firm's assessment of different modes and ultimately its choice of a particular mode (Chi and McGuire 1996). Since Kogut (1991), it has been held that the joint venture (JV) as a collaborative form may contain an explicit or implicit option to acquire or divest at a price specified *ex ante*, or more often, negotiated *ex post*. Real options analysis emphasizes the strategic flexibility and learning advantages of collaborative ventures vis-à-vis acquisition or internal development. In a world of uncertainty, by deferring acquisition or internal development, a firm can limit its exposure to adverse market conditions in which the underlying assets of concern such as a technology may turn out to have little value, and limit its exposure to opportunistic partners who may misrepresent the economic value of their assets. At the same time, collaborative ventures provide a mechanism for firms to capitalize on growth opportunities through subsequent exercise of the option to acquire the alliance partner or the joint venture.

Folta (1998) examines the conditions under which the benefits of flexibility and learning in equity collaborations in the biotechnology industry outweigh the benefits of superior administrative control from internalization. Folta (1998) finds empirically that exogenous technological uncertainty leads to a preference for equity collaboration over acquisition. Further, equity collaborations provide a better mechanism for learning through sequential investments than outright acquisition.

Real options theory also has strategic implications for the governance choice between integration and market contracting. Under uncertainty, market-like mechanisms may incur greater short-term marginal production costs than integration but may provide greater strategic flexibility whose value increases with uncertainty (Leiblein 2003). In addition, firms with a broader product-market scope have an enhanced capability to respond flexibly to changes in market demand. Specifically, with small toehold investments in multiple product markets, even if demand falls short of projections for a vertically integrated business, the manufacturing facility may be converted for use in other product-markets with lower switching costs. For these reasons, Leiblein and Miller (2003) find empirically that semiconductor firms with switching options provided by broader product-market scope are more likely to choose internal production over sourced production. This effect of switching options on the likelihood of internal production is independent of the effects of traditional transaction cost and organizational capabilities factors.

Option rights in collaborative ventures

The most widely analyzed governance structure in real options is probably inter-organizational collaboration, including joint ventures and strategic alliances (see also Cuypers and Martin 2007). Much research in this stream has focused on the value of option rights in collaborative ventures. According to Chi and McGuire (1996), a necessary condition for the option to acquire or sell out a collaborative venture to provide a positive economic value for its partners is that the partners have divergent economic valuations of the venture *ex ante* or anticipate a divergence of their *ex post* valuations. Under *ex ante symmetry* the two partners benefit equally from the option to acquire or sell, and there is no reason to designate only one of them as the option holder in their contract. *Ex ante* anticipation of the possibility of *ex post* divergence can by itself be one of the motives for initiating a collaborative venture in the first

place (Chi and McGuire, 1996; Chi, 2000)².

The divergence of economic valuations can be attributed, among other factors, to greater complementarity of one partner's assets to those of a collaborative venture (Kogut, 1991) or to partners' differential learning capabilities in taking advantage of uncertainty over the returns of the collaboration. While market uncertainty is largely exogenous to investment choices, endogenous uncertainty exists over the capabilities of partners (Chi and Seth 2004) or over the behavioral tendencies of partners in a world of information asymmetry and opportunism (Chi and McGuire 1996). The economic value of options embedded in collaborative ventures is a positive function of the uncertainty involved because greater uncertainty increases the value of the capability to incorporate any newly gathered information into managerial decisions. In particular, greater endogenous uncertainty also implies greater opportunities for learning through collaboration. Therefore, uncertainty is an important driver for the value of the option to acquire or divest a collaborative venture.

While existing research on learning races (Hamel, Doz, and Prahalad 1989) suggests that asymmetric learning only benefits one partner, asymmetric learning from a real options perspective may benefit both partners, as such asymmetry may lead to the trading of options that can create joint gains to both partners (Chi 2000). Specifically, the more capable party is better able to earn economic rent from the JV's assets and is hence willing to pay a higher price for the assets than is the other party. Chi and Seth (2004) show, however, that asymmetric learning can be value-destroying if the partners are more motivated to invest resources in power-jockeying when they anticipate a substantial wealth transfer after the occurrence of asymmetric learning.

In addition to the research on the value of option rights in collaborative ventures and its

² Concerning the reason for exercising the option to acquire, Kogut (1991) observes that the reason for a JV partner to buy out the other is likely to be the existence of a difference between their *ex post* evaluations of the JV's assets.

implications for governance choice, real options studies, in combination with transaction cost economics, shed insights on other contractual issues such as the assignment of option rights and allocation of equity stakes in collaborative ventures. Concerning which partner should hold the option to acquire in an international joint venture (IJV) involving technology transfer from the multinational to the local firm, Chi and McGuire (1996) propose that the multinational is more likely to hold the option to acquire when the intellectual property rights regime is less adequate in protecting the multinational from potential misappropriation of its technology. When the appropriability regime is weak, by limiting the scale and scope of technology transfer in the beginning, the multinational can use the joint venture to assess the local firm's capabilities and behavioral tendencies before it makes any major effort in technology transfer. More generally, Chi (2000) shows that the party that experiences greater uncertainty about the value of the assets in a collaborative venture should be given the call option to acquire or the put option to divest, no matter whether the party is the high or low bidder for the joint venture assets. The party that has less information on—and hence experiences greater uncertainty about—the value of the assets can benefit more from holding the right to acquire/divest the assets than can other partners.

Concerning the relationship between option rights and allocation of equity stakes, Chi and McGuire (1996) propose that a JV-partner holding only an option to acquire will prefer its equity share to be as *low* as possible. Since the option to acquire at a fixed price enables the option holder to utilize the venture's upside potential, a smaller initial share reduces its exposure to the venture's downward risk while still allowing it to benefit fully from the venture's upside potential. Since the option to sell out at a fixed price enables the option holder to cover the venture's downward risk, a larger initial share allows it to benefit more fully from the venture's upside potential while still covering its exposure to the venture's downward risk.

Given that an option clause in the JV or alliance contract can protect the economic value of the real options embedded in a collaborative venture from being dissipated by *ex post* bargaining, does it imply that the partners should always include such an option clause in their contract? Seth and Chi (2005) suggest that because of economic incentive problems, partners would be reluctant to explicitly specify option rights *ex ante* under significant uncertainty. Seth and Chi (2005) provide the following four reasons. First, there are costs of including such a clause if at the time of JV-formation it is unclear which party will have the higher valuation of the JV's assets. Second, if the parties expect to have significantly more information about the appropriate price *ex post*, then the relative cost of negotiating the price *ex ante* is likely to be higher. Third, a price negotiated under more imperfect information is more likely to be inappropriate. If the exercise price of a call option is set too low, then the option issuer is likely to lose economic incentive to contribute too early, because the assets' value to the call-option holder is likely to exceed the exercise price well before the benefit from the option issuer's effort is fully realized. Similarly, if the exercise price of a put option is set too high, then the option holder is likely to have little economic incentive to maintain the value of the assets, because the high exercise price already guarantees the party a high return. Fourth, partners may have to place restrictions on one or both of them with regard to their exercise of the option to acquire the other's stake via *ex post* negotiation, because the anticipation of such negotiations can motivate them to waste resources in jockeying for power during the alliance process.

Analyzing international joint venture (IJV) transactions from 36 different host countries and a US partner, Reuer and Tong (2005) find that the percentage of IJVs with explicit options is roughly one percent and is fairly stable from year to year. The percentage of IJVs with explicit calls is higher for IJVs in which the U.S. party owned less than 50% of the venture's equity.

Explicit call options are used more often in IJVs that fall into firms' core businesses, but less in IJVs based in host countries with a tighter intellectual property rights regime and greater political risk.

Valuation and performance implications of real options

Real options theory is fundamentally a theory of economic valuation. Since Miller and Modigliani (1961) and Myers (1977), it has been posited that the economic value of a firm derives not only from its assets in place but also from its future discretionary investment opportunities or corporate growth options. The value of growth options can be substantial. Kester (1984) observes from financial data that growth options constitute well over half the market value of many companies' equity. Pindyck (1988) also shows through numerical simulation that growth options account for a substantial fraction of market value and that this 'growth' component of firm market value increases with demand volatility.

Myers (1984) emphasizes that it is difficult for the traditional NPV or discounted cash flow (DCF) method to play a role in strategic planning because of the DCF's inability to evaluate the time-series interactions between investments that involve high-growth, intangible assets. Real options theory recognizes the strategic value of managerial flexibility to take alternative courses of action over time. Such actions include, but are not limited to, delaying investment, investing sequentially for corporate growth options, abandoning and switching. Trigeorgis (1996) proposes an expanded NPV framework in which the economic value of an investment consists of direct static NPV, the value of strategic commitments, and the value of flexibility/ real options.

Valuation

Although a large number of research studies in financial economics have applied discrete binomial and continuous Black-Scholes-Merton option pricing models or their variants to

evaluate firms, businesses and projects, management studies directly applying these analytical models are scarce. One such study by Seppa and Laamanen (2001) tests the applicability of a simple binomial model in valuing venture capital investments. The empirical results of the binomial valuation model are consistent with the existing evidence on the risk-return profile of venture capital investments. Specifically, the risk-neutral probabilities of success are smaller for early-stage ventures and positively related to the number of prior financing rounds, whereas implied volatility is larger for early-stage ventures and are negatively related to the number of prior financing rounds. Importantly, Seppa and Lammanen (2001) find that the simple binomial model outperforms the traditional risk-adjusted NPV models in forecasting the economic returns for the sample ventures.

Performance implications of real options

In general, however, the option pricing models may not be readily applicable to real investments because of some key differences between real and financial options (Bowman and Moskowitz 2001; Lander and Pinches 1998). Indeed, most strategic management studies have focused on whether and how organizations can benefit from creation and exercise of real options and growth options in particular, embedded in projects, businesses and firms. For example, Bowman and Hurry (1993) propose that organizations that enter new businesses and markets by linking investments — so that small options are followed by large strikes — will perform better than those entering with only discrete small, or large, investments. Further, firms are expected to perform the best if they exercise an option with the right timing, which is determined by the expiration date of the option and arrival of the opportunities (Bowman and Hurry 1993).

Several empirical studies have examined whether and under what conditions firms with embedded real options will be valued by market investors. Levitas and Chi (2001) analyze when

patents, conceptualized as conferring real options to owners, would contribute to firm market value. Levitas and Chi (2001) suggest that patents provide positive indications about a firm's future strategic possibilities or real options but provide dubious and potentially negative information about other aspects of a firm's overall value. In line with the standard options view that the economic value of an option increases with uncertainty, Levitas and Chi (2001) observe that firms that have signaled the possession of technological competence through patenting have higher market value in more volatile environments.

Tong, Reuer and Peng (Forthcoming) examine whether and when IJVs confer valuable growth options to firms. For multinationals considering international market entry, IJVs are attractive not only because of their capability to reduce downside risk, but also because they enable firms to access upside opportunities by expanding sequentially as new information on key sources of uncertainty becomes available. Therefore, they propose a positive effect of the number of IJVs on the firm's growth option value. In line with the logic that the value of options increases with uncertainty, Tong, *et al.* (Forthcoming) discuss three situations where IJV partners can manage uncertainty and leverage emerging opportunities. First, a lower ownership level reduces the firm's downside risk in the collaboration, while still allowing the firm to benefit from the venture's upside opportunities. Second, growth options are more salient in new and exploratory activities because such diversifying activities are easier to manage and imply heightened uncertainty in exploratory environments. Third, the higher levels of uncertainty in emerging economies may elevate the growth option value of IJVs in such locations. The empirical results show that IJVs, and those minority IJVs and diversifying IJVs in particular, enhance multinationals' growth option value.

The above two studies (Levitas and Chi 2001; Tong *et al.* Forthcoming) have followed Myers (1977) and Kester (1984) to examine whether and how the market value of an ongoing concern might be increased by future discretionary opportunities beyond the assets in place. As uncertainty about future cash flows is resolved, however, investors might choose to abandon their investments in a project, business or a firm.

Berger, Ofek and Swary (1996) examine whether market investors value the option to abandon a firm. As expected, they find that firms with greater exit value and less specialized assets are worth more to investors after accounting for the present value of expected cash flows. Further, the abandonment option value is expected to increase with the probability of this option being exercised. If there is no probability of exercise, information about exit value should have no value to investors. At the other extreme, when the option is certain to be exercised, an extra dollar of exit value should increase market value by exactly one dollar. Therefore, Berger, *et al.* (1996) hypothesize that the higher the probability of the option being exercised, the more pronounced effects will variation around a given level of exit value have on market value. Indeed, the empirical results show that firms with higher probabilities of financial stress or timely abandonment have market values that are more sensitive to variation in estimated exit values.

Kumar (2005) examines when terminating a JV via acquisition or divestment creates value for partners. Terminating ventures in uncertain industries would create less value, since it pays to 'keep options open' under uncertainty. Kumar (2005) finds for JV terminations a negative relationship between uncertainty and firm value, measured as the abnormal return prior to the announcement date of JV termination. In addition, the options value increases with the time to maturity, but the options provided by the JV are likely to expire sooner when there is

more rivalry. Therefore, a negative effect of competition on the value of acquirers or those divesting is expected. The empirical results show that terminating ventures in concentrated industries (with less competition) create less value.

Real options theory holds that flexibility is economically valuable under uncertainty and implies that investments that enhance flexibility under uncertainty will add economic value to option holders. For example, multinationals possess options unavailable to purely domestic firms since multinationals can shift value chain activities within their networks of subsidiaries and achieve production flexibility across borders (Kogut 1983; Kogut and Kulatilaka 1994a). Miller and Reuer (1998a) find from cross-sectional analyses that foreign direct investment reduces economic exposure to foreign exchange rate movements. Further, if firms behave as real options theory suggests, those with significant exposures to foreign exchange rate movements should manage their exposures in such a way that firms can take advantage of currency movements that increase firm value while adequately hedging exchange rate movements detrimental to firm value. Indeed, Miller and Reuer (1998b) do not observe symmetric exposures for appreciation and depreciation of foreign currencies and find that for the small percentage of U.S. manufacturing firms exposed to currency appreciations or depreciations, their exposures are asymmetric.

Potential benefits of options strategies include both access to upside growth opportunities and containment of downside risks. In addition to multinationality that provides production flexibility, IJVs also enable firms to make an incremental initial commitment to a market or technology and to expand that commitment if the market or technology proves to be favorable. Therefore, Reuer and Leiblein (2000) hypothesize that a firm's multinationality and investments in IJVs will enable the firm to curtail downside economic risk, measured as below-target

performance (ROA and ROE). The empirical results, however, do not provide support for this claim. As Reuer and Leiblein (2000) point out, the empirical results can be explained in at least two ways. First, strategies that are consistent with real options theory (and other theories) may not always result in superior economic performance. The potential strategic flexibility offered by multinationality and IJVs may not be realized for organizational and other reasons or is not economically valuable if uncertainty is not significant. This explanation points to the importance of identifying the contingency factors that determine the economic value of real options. Second, dispersed foreign investments and IJVs may not be motivated by concerns about the potential switching options and growth options embedded in multinational operations and IJVs in the first place, but rather by other demand- and competition-related factors.

In sum, few strategic management studies have directly applied option-pricing models to value projects, businesses or firms. Most research studies have examined whether and when option creation and exercise benefit option holders, whether the benefit is in terms of growth options value or foreign exchange hedging. These research studies have provided some but sometimes mixed empirical evidence about the benefits of strategies consistent with real options theory.

LOOKING AHEAD: THE FUTURE OF REAL OPTIONS IN STRATEGIC MANAGEMENT RESEARCH

Not all investments can be *usefully* analyzed from a real options perspective. Real options theory generally applies in contexts that are characterized by uncertainty and managerial discretion (Dixit and Pindyck 1994; Kogut and Kulatilaka 1994b; Trigeorgis 1996). We believe that as an emerging area of research, real options entail great upside potential for the field of Strategic Management. To make real options studies relevant and valuable to management

research and practice, it is also important to recognize the potential pitfalls and contain the downside risks in applications of real options theory.

The real options theory of investment

Traditional NPV analysis does not properly account for real options embedded in investment projects, businesses, and firms. The real options theory of investment holds that investment and exit decisions are influenced not only by the expected NPV but also by the options value drivers, i.e., the strategic factors that determine the economic value of real options embedded in investments. This current review has showed how research on firm-level investment behavior would benefit from consideration of common real options, such as option to wait-to-invest, options to abandon and switch, and corporate growth options. Further, extant research has also revealed some important real options value drivers, such as uncertainty, irreversibility, growth potential and competition. A number of research studies in management have examined the effects of these factors on investment decisions in various business contexts.

We identify several areas of future research that we believe would advance both real options theory of investment and strategic management research. First, it remains a promising area to examine the relationship between real options, learning and firm-level heterogeneity in resources and capabilities. For example, from a resource-based view, one may argue that management of real options requires managerial discretion that is enabled and constrained by firm-specific resources and capabilities (Mahoney 2005). Because of the heterogeneity in resources and capabilities (including learning capabilities), different firms facing the same opportunity may display different investment patterns in relation to option creation and exercise (Bowman and Hurry 1993).

Second, opportunities exist for analyzing investment decisions from an integrated real

options and game-theoretic perspective. Real options are usually shared, and their economic value may be eroded by competition. In this regard, an increasing number of theoretical studies integrating real options and game theory has emerged since the 1990s (e.g., Grenadier 2000; Smit and Trigeorgis 2004). Management studies have so far made some progress in this area of research. In general, however, recent theoretical developments seem to have advanced ahead of empirical research. In addition, it is interesting to examine how competition would influence a sequential investment process as uncertainty changes over time. Further, little research exists that actually analyzes the effects of competitive dynamics on option creation and exercise. We believe that research studies along these lines will not only enhance our understanding of the interaction between real options and competitive dynamics but also enlighten our understanding of a fundamental dilemma in investment decisions between commitment, which is a focus of game theory, and flexibility, which is a focus of real options theory.

Third, we encourage more real options research on exit/ abandonment decisions. There are at least two reasons. The first reason is that research studies have focused more on investment than on exit, abandonment or divestment. As we discussed above, real options theory has offered some interesting predictions about uncertainty, irreversibility and exit decisions. Also, except for the research studies on importing and exporting adjustments to exchange rate volatility, it remains under-explored whether firms abandon their projects or businesses in such a way as predicted by real options theory. The second reason is that research studies along this line would further our understanding of the differences and similarities between the predictions of the escalation of commitment and real options theories concerning delayed exit.

Real options theory is a theory on organizational investment decisions rather than on individual decisions that is the focus of the escalation of commitment theory. Further, real

options theory focuses on ‘inaction’ in the form of exit delay that is regarded as a rational reaction to conditions of uncertainty and irreversibility whereas escalation of commitment literature focuses on escalation or increased commitment caused by equivocal feedback and regarded as violating ‘rationality’. Finally, real options theory, as a theory of dynamic investment decisions, suggests that under conditions of uncertainty and irreversibility, there is a higher likelihood that 1). Investments are delayed; 2). Exits are delayed; and consequently 3). The ‘zone of inaction’ widens. Therefore, while both theories predict delayed exit, future research may also examine whether the ‘zone of inaction’ widens with uncertainty and irreversibility. Such a comprehensive investigation of the implications of real options theory considers organizational investment behavior during the whole investment process from investing to exiting. Future studies along these lines, whether in a large-sample statistical analysis or in a controlled experimental study as in Bragger *et al.* (1998), would contribute to real options theory of investment and to strategic management.

Fourth, research studies have started to examine the interaction between real options (e.g., Folta and O’Brien, 2004) as well as the interaction between option-like projects (e.g. MacMillan and McGrath 2002; Vassolo *et al.* 2004). Future research may analyze from a real options perspective how organizations build their portfolios of projects and businesses (Childs and Triantis 1999). More generally, we believe that both real options interactions and portfolios of options warrant more theoretical and empirical studies because firms often manage a portfolio of projects simultaneously or sequentially.

Finally, although research studies have provided largely supportive evidence for a real options theory of investment concerning the effects of real options value drivers on investment decisions, future research is needed to tackle some empirical inconsistencies. For example, both

Favero, Pesaran and Sharma (1994) and Hurn and Wright (1994) examine when to develop a discovered oil reserve with significant price uncertainty. Favero, *et al.* (1994) find a non-linear effect of uncertainty: Increased price volatility has a positive impact on the duration between the discovery of the oil reserves and the time of approval for development when expected prices are low and a negative impact on the duration when expected prices are high. In contrast, using data on oil reserves on the North Sea, Hurn and Wright (1994) find that oil price variance has a negative effect on the duration but is statistically insignificant. Similarly, while Campa (1993) does not find a non-monotonic effect of exchange rate volatility on the number of foreign entries, Folta and O'Brien (2004) find that uncertainty has a U-shaped effect on market entry. These mixed empirical results may be attributed to various theoretical and empirical issues. Here, we focus our discussion on the sources and measures of uncertainty.

Uncertainty is central to real options theory of investment and it has important influence over investment behavior regardless of individual risk-preferences (Dixit and Pindyck 1994). However, real options theory itself does not specify the sources of uncertainty. This ambiguity creates difficulties for research studies as to what are the most relevant and important sources of uncertainty. Uncertainty may be attributed to market demand or technological development; uncertainty may be exogenous or endogenous, uncertainty may be firm-specific or industry-specific, and so on. We welcome future studies that examine the individual and interactive effects of multiple sources of uncertainty on investment decisions. In addition, extant research studies do not have a consensus on the empirical measure of uncertainty. Real options studies have so far employed various measures such as simple variance (or standard deviation) (e.g. Campa 1993; Folta 1998), conditional variance from an ARCH or GARCH process (e.g. Folta and O'Brien 2004), squared residuals or standard error of regression (e.g. Favero *et al.* 1994;

Hurn and Wright 1994), or some context-specific measures (e.g. Kumar 2005). Each of these measures has its strengths and shortcomings (cf. Carruth *et al.* 2000). We encourage future studies to use multiple measures of uncertainty, where proper, for robustness checks.

Real options studies about investment mode choices

Real options theory has offered additional insights into the choice of investment modes and into contractual issues. The conceptualization of collaborative ventures as creating call options has been central to this contribution. Real options theory focuses on the strategic flexibility and learning benefits of collaboration under uncertainty, in contrast with other views such as transaction cost economics that highlights *ex post* misappropriation or hold-up problems (Pisano 1990; Williamson 1985). Real options theory has also provided a more dynamic view on governance structures than currently found in transaction cost economics. According to real options theory, JVs may be used as transitional mechanisms towards acquisition or internal development and termination of JVs may not signal failures in collaboration but exercise of expansion or growth options (Kogut 1991). Finally, from a real options perspective, asymmetric learning may not lead to ‘learning races’ but to divergence of valuations that provides opportunities for ‘trading’ option rights.

Future research in this area may build on these insights to examine governance choice and contractual issues. In particular, as a complementary approach to transaction cost economics, real options theory can be used to analyze contractual issues for uncertain investments, such as the specification and assignment of option rights in alliances and venture capital investments.

The performance implications of real options

Real options theory posits that the economic value of real options may comprise a

significant fraction of the economic value of a project, business or firm. Research opportunities to amplify and extend this postulate exist in several areas.

First, extant research has found some perplexing evidence concerning the predictions of real options theory about organizational performance. For example, while Miller and Reuer (1998a, 1998b) find supportive evidence for real options reasoning in terms of FDI's reducing exposures to exchange rate volatility and firms managing exchange rate exposures asymmetrically, Reuer and Leiblein (2000) does not find evidence that multinationality reduces organizational downside risks. Resolving such inconsistencies may bring about new insights and advance the field.

Second, creation and exercise of real options incur costs. While most research focuses on the benefits or positive performance impact of options-like investments, costs of such investments have been seldom addressed. Since the value of options (or flexibility) is always nonnegative or positive, there may be a misconception that options reasoning can be used to justify any investments. In reality, it might be too costly to obtain an option in the first place. Future research studies along these directions would provide a more comprehensive understanding of the performance implications of real options investment strategies.

Third, more research is needed to examine firm- and industry-level influences on the performance of options-like investments. Studies have shown that capturing the economic value of real options also depends on firm- and industry-level contingencies (e.g., Tong and Reuer, 2006).

Finally, we encourage further applications of real options theory, whether such applications are concerned with investing and exiting decisions, governance choice, or performance implications of real options. In fact, real options theory has been widely applied to

analyze market entry (e.g. Folta and O'Brien 2004), equity joint ventures (e.g. Chi and McGuire 1996; Kogut 1991; Reuer and Leiblein 2000), foreign entry and multinational operations (e.g. Allen and Pantzalis 1996; Campa 1994; Miller and Reuer 1998b; Rangan 1998; Rivoli and Salorio 1996), R&D/ patenting decisions (McGrath 1997; McGrath and Nerkar 2004), and corporate growth value (e.g. Tong *et al.* Forthcoming). Other applications may include venture capital and entrepreneurship, which both involve uncertain outcomes and managerial discretion. Real options reasoning may serve as a heuristic framework to practitioners for experimentation, managerial oversight, and proactive exploration of uncertainty (Bowman and Moskowitz 2001; McGrath 2001). Accordingly, real options theory can become an important theoretical perspective towards venture capital and entrepreneurship (Hurry, Miller, and Bowman 1992).

Implementation of real options in theory and practice

Although real options theory offers a compelling framework to analyze irreversible investments under uncertainty and their economic performance implications, real options analysis can present formidable problems for implementation in both theory and practice (Bowman and Moskowitz 2001; Lander and Pinches 1998). In the following, we first discuss the major issues concerning the applicability of the option pricing models in strategic decision-making, and then discuss problems concerning the influence of organizational and psychological issues on real options applications in practice.

Regarding the application of quantitative option pricing models to strategic investments, the problems generally fall into three categories (Bowman and Moskowitz 2001; Lander and Pinches 1998): finding an options pricing model whose assumptions match those of the project being analyzed, determining the proper measures for the variables of this model, and being able to solve mathematically the option pricing model. The complexity of real world investments and

the accompanying complexity of the model can make it difficult to identify errors in the analysis or inconsistencies in underlying assumptions, and thus present challenges for managers.

Real options analysis can also serve as a check against other financial and strategic decision tools. Nonetheless, application of real options in practice involves organizational processes that may be characterized by incentive problems and cognitive limitations. These factors may impede management of real options for evaluation of investments in strategic opportunities for which uncertainty resolution is endogenous to firm action, the scope of possibilities is vast, and the option termination date is not pre-specified (Adner and Levinthal 2004). For example, given the often open-ended nature of investment opportunities, some rigidity in the specification of allowable courses of action is needed to offset the flexibility of abandonment. Yet at the same time, imposing rigid criteria may hinder discoveries that may not be useful for the current investment agenda, but may create possibilities not previously conceived (Adner and Levinthal 2004).

Real options theory, with its origin in financial economics, is not a theory that focuses on organizational processes. Further, no decision-making framework can guarantee a ‘good’ outcome and there is no substitute for managerial efforts and discretion (Lander and Pinches 1998). It is thus critical to consider various organizational and psychological issues that may complicate the application of real options and point to the boundaries of real options theory (Adner and Levinthal 2004).

Concerning organizational pre-requisites to successful real options strategies, Amram and Kulatilaka (1999: 209-210) pose three questions that point to promising research opportunities — *Who controls the decision rights to the option? What changes in the firm’s processes are needed to manage real options? What changes in the organization are needed to capture the*

option value? Each of these questions addresses crucial aspects of the organization that need to be in tune with a strategy that is based on the real options theory. Since economic incentive problems, psychological biases, and other organizational issues may influence firms' decisions concerning option creation, option exercise and management of option portfolios (Adner and Levinthal 2004; Coff and Lavery 2001; Garud, Kumaraswamy, and Nayyar 1998; Miller and Shapira 2004; Trigeorgis 1996), future field and case studies in addressing the practical implementation of real options are particularly useful to our understanding of applications of real options theory in practice.

CONCLUSION

In this paper, we considered recent developments in real options theory and focused on its applications in strategic management research. The current study also identified several promising areas for future research concerning investment decisions, governance choice and performance implications. While real options theory has recently witnessed debates about the applicability of option pricing models to strategic decision-making and the complications brought by organizational and psychological factors that influence managerial discretion in option creation and exercise, we do not see significant challenges concerning the validity of real options theory as a sound conceptual lens for explaining and predicting strategic decision-making under uncertainty. We do, however, recommend timely research to address implementation issues in a theoretically deep and empirically sound manner.

Two decades ago, Myers (1984) proposed that real options theory as a unique perspective could be used to bridge financial theories with strategic management. Our discussion shows that since then real options theory has provided substantial insights into topics of central concern to

strategic management research, such as investment and exit decisions and the choice of investment modes. In addition, extant research studies have contributed significantly to our understanding of whether and under what conditions organizations can benefit from real options embedded in projects, lines of business, and firms. We call for future generations of research that we hope would enhance the impact of real options as an emerging dominant conceptual lens in strategic management.

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TABLE 1
Applications of Real Options Theory in Strategic Management

KEY TOPICS	THEMES	ILLUSTRATIVE STRATEGY STUDIES
Common real options and investment decisions	Investment opportunities as real options	Dixit & Pindyck (1995)
	Option to wait-to-invest	Folta & O'Brien (2004); Rivoli & Salorio (1996)
	Options to abandon and switch	Chi & Nystrom (1995); Kogut (1983); Kogut & Kulatilaka (1994a); Miller & Reuer (1998a, b)
	Growth options	Kogut (1983; 1991); McGrath (1997); McGrath & Nerkar (2004); Miller & Folta (2002)
	Interaction of real options	Folta & O'Brien (2004)
Extensions of real options theory of investment	Portfolios of options	Bowman & Hurry (1993); MacMillan & McGrath (2002); McGrath & Nerkar (2004); Vassollo, Anand & Folta (2004)
	Competition and investment	Folta & Miller (2002); McGrath & Nerkar (2004); Smit & Ankum (1993); Smit & Trigeorgis (2004)
	Endogenous uncertainty and learning	Bowman & Hurry (1993); McGrath (1997); Sanchez (1993)
	Exit decisions and hysteresis	Bragger, Bragger, Hantula & Kirnan (1998)
Organization and governance	Choice of investment modes	Chi & McGuire (1996); Folta (1998); Kogut (1991); Leiblein (2003); Leiblein & Miller (2003)
	Option rights in collaborative ventures	Chi (2000); Chi & McGuire (1996); Chi & Seth (2004); Reuer & Tong (2005)
Valuation and performance	Valuation	Seppa & Laamanen (2001)
	Performance implications	Berger, Ofek & Swary (1996); Kumar (2005); Reuer & Leiblein (2000); Tong, Reuer & Peng (<i>forthcoming</i>)

FIGURE 1
TAKING STOCK AND LOOKING AHEAD: A READER'S ROADMAP

