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Real Options Theory

Jeffrey J. Reuer and
Tony W. Tong

REAL OPTIONS THEORY

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REAL OPTIONS THEORY

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PART I:
INTRODUCTION

REAL OPTIONS IN STRATEGIC MANAGEMENT

Tony W. Tong and Jeffrey J. Reuer

A fundamental issue in the field of strategic management concerns firms' strategic choices and directions (Rumelt, Schendel, & Teece, 1994). Reflecting this central concern, a substantial amount of research in the field has examined the antecedents of a wide range of strategic decisions by firms as well as their performance implications. Whether strategic decisions involve internal investments in technology or external corporate development activities, they generally involve resource commitments to future initiatives under uncertainty. As a result, the role of uncertainty has received a great deal of attention in strategy research, and there has been recurrent interest in how firms might better manage strategic decision making under uncertainty.

Research has long recognized the key role that uncertainty plays in organizations and management (e.g., Cyert & March, 1963; Thompson, 1967), yet a recent and novel treatment of uncertainty comes from real options theory. In contrast to traditional views that managerial discretion is limited in the face of uncertainty or that organizational inertia dominates, real options theory maintains that firms can engage uncertainty and benefit by investing in options to respond to uncertain futures and by managing the investments in a sequential fashion as uncertainty is resolved (Kogut, 1991; Dixit & Pindyck, 1994; Kogut & Kulatilaka, 2001). Recent advances in strategy and finance have suggested that real options theory potentially offers a powerful valuation tool as well as a systematic strategy framework

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to evaluate and structure resource investments under uncertainty, and that successful use of real options can lead to the benefits of downside risk reduction and upside potential enhancement (Bowman & Hurry, 1993; Kogut & Kulatilaka, 1994a; Trigeorgis, 1996; McGrath, 1997; Amram & Kulatilaka, 1999).

In undertaking this volume, our objectives are two-fold. First, as interest in real options theory continues to grow, there have also been questions on the greater promise of real options theory in strategy. While advocates believe that real options theory informs strategic decision making under uncertainty, others also see difficulties surrounding the theory's larger applicability to strategic management issues. We suggest that part of this dialogue reflects broader questions on how real options theory might link to the foundations of the strategy field, and we identify four fundamental questions for real options theory to advance in strategy. Second, the strategy literature on real options has developed rapidly, and research has examined diverse aspects of the theory. As such, our second objective is to catalog, synthesize, and critique the extant real options research in strategy. This effort can delineate the ways in which real options theory contributes to strategy, and it also can reveal certain avenues for future research on real options. The focused volume therefore can provide a forum for researchers to tackle key questions, discuss promising opportunities, and map out the future research agenda for real options theory in strategic management.

In the following section, we briefly review the origins of real options theory, trace its developments in strategic management, and outline three reasons why it has become important for the field. This review and assessment leads to an overarching framework that we also use to organize the remaining 17 chapters in this volume, and we highlight how these articles are built on the framework and contribute to our expanded knowledge. We conclude by offering four fundamental questions that we believe lie at the interface between real options and strategy and can help move forward real options research in strategy in important ways.

THE DEVELOPMENT OF REAL OPTIONS THEORY

The Origins of Real Options Theory

Real options theory begins by drawing an analogy between real options and financial options. A financial option is a derivative security whose value is derived from the worth and characteristics of another financial security, or the so-called underlying asset. By definition, a financial option gives its holder the right, but not the obligation, to buy or sell the underlying asset at a specified price (i.e., the exercise price) on or before a given date (i.e., the expiration date). Financial economists Black and Scholes (1973) and Merton (1973) pioneered a formula for the valuation of a financial option, and their methodology has opened up the subsequent research on the pricing of financial assets and paved the way for the development of real options theory.

The notion of real options was developed from Myers' (1977) seminal idea that one can view firms' discretionary investment opportunities as a call option on real assets, in much the same way as a financial call option provides decision rights on financial assets. By way of analogy, a real option has as its underlying asset the gross project value of expected operating cash flows; its exercise price is the investment required to obtain this underlying asset; and the time to maturity is the period of time during which the decision maker can defer the investment before the investment opportunity expires (e.g., Myers, 1977; Trigeorgis, 1996). Formally stated, real options are investments in real assets, as opposed to financial assets, which confer the firm the right, but not the obligation, to undertake certain actions in the future (e.g., Trigeorgis, 1996; Amram & Kulatilaka, 1999). Comparisons of financial and real options can be found in standard textbooks (e.g., Brealey, Myers, & Allen, 2006).

Real options research in finance and economics has developed a taxonomy of common real options that are often embedded in an investment, including deferral options, options to stage investments, options to alter operating scale, abandonment options, switching options, and growth options. In addition, an investment frequently involves a combination of some of the common real options above, and their combined value often differs from the sum of the value of each option in isolation (Trigeorgis, 1993). Investments such as technology development or venture capital also may consist of sequential stages, and such multistage investments comprise compound options, whose underlying asset is not a real asset, but another option (Roberts & Weitzman, 1981; Trigeorgis, 1996). To the extent that an investor can hold a portfolio of options simultaneously (Merton, 1973), a firm undertaking multiple investments at a point in time may also experience option portfolio interactions, in that options embedded in one investment may shape the value of other options held by the firm and therefore the overall value of the option portfolio (e.g., Triantis & Hodder, 1990; Luehrman, 1998; Smit & Trigeorgis, 2004).

The real options literature in finance and economics tends to have an analytic focus, employing real options analysis to evaluate firms' investments under uncertainty and to model the optimal conditions for undertaking such investments. For example, earlier research in this literature has evaluated investments in natural resources and flexible manufacturing (e.g., Brennan & Schwartz, 1985; Triantis & Hodder, 1990), analyzed the optimal timing of investing in land development (e.g., Titman, 1985), and studied the relationship between options to alter operating scale and the value of the firm (e.g., McDonald & Siegel, 1985; Pindyck, 1988; Majd & Pindyck, 1989). Pindyck (1991) and Dixit (1992) reviewed the literature on investment under uncertainty, and Dixit and Pindyck (1994) provided extensive discussions of theoretical advances. Two recent developments relating to strategy are noteworthy, however. First, research has paid increasing attention to the competitive environment surrounding firms' investments and the strategic aspects of real options, which have important implications for competitive strategy (e.g., Kulatilaka & Perotti, 1998; Grenadier, 2000; Smit & Trigeorgis, 2004). Second, research has also used real options theory to analyze investments in building strategic resources such as R&D, as well as other corporate development activities such as acquisitions and diversification, in the broader context of corporate strategy (e.g., Childs & Triantis, 1999; Matsusaka, 2001; Bernardo & Chowdhry, 2002; Pacheco-de-Almeida & Zemsky, 2003).

Compared to the large amount of theoretical work in this literature, there have been relatively few large-scale empirical studies, a point lamented by Schwartz and Trigeorgis (2001) and others. The available empirical analyses of real options in finance and economics have largely continued the focus of analytic work in the areas of natural resource investments and real estate development (e.g., Paddock, Siegel, & Smith, 1988; Quigg, 1993; Moel & Tufano, 2002), and have also examined the implications of particular options for the value of the firm (e.g., Berger, Ofek, & Swary, 1996). Empirical work on investing in strategic resources and corporate development is lacking, however, and option implementation issues related to organization, incentives, and the like have yet to be probed in more depth (Trigeorgis, 1996).

The Development of Real Options Theory in Strategic Management

Initial interest in real options in the field of strategic management began to emerge in the early 1980s, when management researchers first expressed dissatisfaction with traditional financial techniques such as the net present value (NPV) approach to resource allocation and strategic decision making (e.g., Hayes & Garvin, 1982). These techniques make it hard to account for follow-on investment opportunities often embedded in a corporate investment project, or to capture managers' flexibility in adapting their decisions to evolving market and technological uncertainty, a view also shared by financial economists such as Myers (1984) and Kester (1984).

Kogut was among the first to formally conceptualize and empirically test real options in strategic management. His seminal work started in the context of multinational corporations (MNCs) and the coordination of their operations across countries. In a series of articles, Kogut (1983, 1985, 1989) maintained that multinational operations confer the MNC a string of real options in order to capitalize on the high levels of uncertainty and heterogeneous opportunities present across countries. For instance, he suggested that international investment confers the MNC valuable growth options, and an initial investment in a foreign country often carries a large option value, since the investment can unlock opportunities for future expansion. Kogut also emphasized that the MNC holds a portfolio of switching options that offer operating flexibility by allowing the firm to shift value chain activities across geographically dispersed subsidiaries as uncertain environmental conditions evolve.

A number of studies have expanded Kogut's initial contributions in several concrete ways. Kogut and Kulatilaka (1994a), for example, developed a model that captures the option value of production switching between two country locations in the presence of volatile exchange rates. Kogut and Chang (1996) empirically tested the idea that an initial investment may serve as a platform for subsequent expansion, and they found that Japanese firms' direct investments in the U.S. were triggered by appreciation of the Japanese yen. Miller and Reuer (1998a, 1998b) studied U.S. MNCs' economic exposures to foreign exchange rate movements, and they showed that firms with greater FDI have lower exposures, and that such exposures also tend to be asymmetric, which is consistent with the presence of real options. Allen and Pantzalis (1996) and Tang and Tikoo (1999) provided evidence that the stock market values the breadth of MNCs' international operations, supporting the notion of switching options available to the firms. More recently, Reuer and colleagues couched the benefits of operating flexibility in terms of the downside risk reduction from multinational investments (Reuer & Leiblein, 2000; Tong & Reuer, 2007), and they suggested and found that the extent to which MNCs can benefit from geographically dispersed operations is tempered by certain organizational factors that increase coordination and switching costs.

Kogut's pioneering contributions also pertained to the areas of governance and organizational choice in the corporate strategy domain. He provided the first theoretical arguments and empirical evidence that joint ventures (JVs) provide firms real options to expand sequentially into new and uncertain markets (Kogut, 1991). By investing in a JV, a firm is able to limit its downside losses to an initial, limited commitment, while also positioning itself to expand, but only if future conditions turn out favorably. In line with the theory, he found that the firm undertakes expansion by exercising the option by buying out its partners when the JV experiences a positive demand shock, but the firm continues to hold onto its investments in the JV when negative demand signals materialize.

A significant amount of theoretical and empirical research that followed has sought to extend this paper by examining the firm's choice of particular governance modes and related governance design issues. First, using formal models, Chi and colleagues have examined the circumstances under which the option to acquire or sell out a JV provides positive economic value for partners, investigated the conditions under which firms may hold the option rights, and analyzed governance structure issues such as the allocation of equity stakes between the partners (Chi & McGuire, 1996; Chi, 2000). Reuer and colleagues studied the real options embedded in various types of JVs (Reuer & Tong, 2005, 2007; Tong, Reuer, & Peng, 2008), and their findings indicated that JVs enhance firms' growth option values, yet only under some well-defined conditions. Second, Folta (1998) studied firms' decisions to undertake JVs versus acquisitions by viewing JVs as providing deferral options and sequential commitments, and he found that firms are more likely to invest in JVs over acquisitions when facing high levels of uncertainty. Folta and Miller (2002) built on Kogut's (1991) focus on option exercise decisions, but went beyond JVs to investigate minority equity investments. Building on Dixit and Pindyck (1994) and continuing Folta's (1998) focus on deferral options, Folta and colleagues examined firms' market entry decisions and presented findings consistent with real options theory (Miller & Folta, 2002; Folta & O'Brien, 2004; Folta, Johnson, & O'Brien, 2006). Collectively, this set of empirical evidence has begun to develop toward a real options theory of market entry and organizational governance that can complement existing theories: market entry modes differ in their attributes and embedded options, and they respond to uncertainty in different ways, leading firms to use them discriminately to structure their investments.

Around the same time as Kogut's work, Bowman and Hurry (1987, 1993) were working to develop an option theory based perspective of strategic management. Bowman and Hurry (1993) proposed options as a strategy heuristic for understanding sequential resource commitments under uncertainty, and central to their theory development is the notion that the options lens "offers an economic logic for the behavioral process of incremental resource investment" (p. 760). Hurry, Miller, and Bowman (1992) found that Japanese venture capitalists tend to make small individual investments, yet a large number of investments, in order to capture a wide range of future opportunities, which they suggested is consistent with an 'options strategy' of seeking new technology. McGrath (1997) advanced a real options logic of technology options by suggesting that firms can make so-called amplifying preinvestments to influence uncertainty to their advantage; in a subsequent paper, she developed the notion that entrepreneurial initiatives can be viewed as real options and suggested that they be managed using real options reasoning (McGrath, 1999). In parallel to some of these lines of research, Kogut and Kulatilaka (1994b, 2001, 2003) aimed to integrate the literatures on real options and capabilities by proposing that real options theory provides a heuristic framing of viewing capabilities as generating platforms to respond to future uncertain opportunities.

Given the strategy field's interest in understanding the actual behaviors of firms (Rumelt et al., 1994), it is not surprising that compared to real options research in finance and economics, research in strategy has paid considerably more attention to issues surrounding option implementation. While in principle real options theory can be applied to evaluate resources and strategic investments that are not publicly traded (Mason & Merton, 1985), strategy researchers have long suggested that various challenges can surround both the valuation and implementation (e.g., creation, maintenance, and exercise) of real options in organizations, in part due to several issues accompanying "domain translation" (Kogut & Kulatilaka, 2004). Indeed, this basic idea finds its roots in the initial contributions in the field and has run through the whole stream of real options research in strategy. For example, Kogut (1985) pointed to the difficulty that managers may have in recognizing valuable options embedded in the firm's investments, a view also shared by Bowman and Hurry (1993). Moreover, just because a firm recognizes the embedded options does not mean that it has the management and organizational system to support their implementation (Kogut, 1989; Kogut & Kulatilaka, 1994a, 1994b). In addition, managers might not use the correct information to assess real options or might evaluate them incorrectly due to the lack of suitable proxies (Bowman & Moskowitz, 2001; Miller & Shapira, 2004). Finally, managerial and organizational factors might further alter option maintenance and exercise decisions: managers may be prone to escalation of commitment, they may not follow the optimal exercise policies due to incentive problems, and they may find it hard to monitor the complex cues for exercise because of bounded rationality (Kogut, 1991; Garud, Kumaraswamy, & Nayyar, 1998; McGrath, 1999; Coff & Laverty, 2001; Adner & Levinthal, 2004).

The Importance of Real Options Theory for Strategic Management

Real options theory provides a set of analytic tools and heuristics to evaluate and deal with the uncertainty that pervades strategic decisions. Indeed, Rumelt et al. (1994, p. 26) identified uncertainty as among the top five "monkey wrenches" that inspired research departing from the neoclassical theory of the firm, and that has given rise to the birth of the strategic management field. Given the essential role of uncertainty in strategic decisions, we suggest that the increased importance of real options theory for strategic management can be explained by at least three factors that may also suggest why real options theory is unique.

First, real options theory requires research to revisit the received wisdom, and offers unique predictions, on firms' decisions for many types of strategic choices under uncertainty. Consider the following three examples. As alluded to earlier, the real options view challenges the traditional perspective of joint ventures as marriages, under which longevity and stability were key indicators of success. According to real options theory, firms can unlock value at the joint venture termination stage, and an important role exists for joint ventures that are transitional investments by design. As a second illustration, foreign direct investment has long been considered a solution to the substantial transaction costs accompanying the market exchange of technology or other assets. By contrast, real options theory instead emphasizes dynamic efficiency gains, downside risk reduction, and the firm's ability to seize upside opportunities over time by shifting value chain activities across borders in response to different uncertainties. Finally, at a more general level, real options theory provides new rules for resource investments by suggesting that real options shift firms' investment thresholds away from the NPV0 criterion. While the details on the threshold effects of various real options have been illustrated elsewhere (Pindyck, 1988; Dixit & Pindyck, 1994; Trigeorgis, 1996), the insight offered by real options analysis can be briefly summarized as follows: a firm may use a reduced investment threshold and decide to invest even if the NPV is negative, if the embedded growth options are sufficiently valuable; by contrast, a firm may use an elevated investment threshold and decide not to invest even if the NPV is positive, if the embedded deferral options are sufficiently valuable and the associated opportunity costs of investing in the current period are significant.

Second, real options theory uniquely posits an asymmetric payoff structure for investments with embedded options by suggesting that real options enable firms to reduce downside risk while accessing upside opportunities. The asymmetry in performance outcomes is due to the discretionary decision rights that options create, i.e., the right to select an outcome in the future only if it is favorable. Compared to other theories, real options theory therefore suggests that the greater the level of uncertainty, the higher the potential payoff to the option holder, given that the initial investment is limited and downside losses are contained (Bowman & Hurry, 1993; Hull, 2003). Another key aspect the theory emphasizes is that maintaining flexibility under uncertainty has option value, and this value can account for a substantial proportion of the value of many investments. Theory and empirical findings also suggest that such option value varies significantly across firms and industries, and of importance to strategic management is what the sources of heterogeneity might be and how option value influences firms' strategic choices and resource allocation policies (Kester, 1984; Tong & Reuer, 2006).

Third, real options theory sheds new light on firms' resource allocation processes by informing strategic decision making. Strategic planning has long embraced such concerns as follow-on opportunities, incremental resource commitments, and sequential management of information and uncertainty, which are all central to firm strategy; yet by their nature planning models lacked the kind of tight decision criteria prescribed by investment models in traditional finance theory. Real options theory can help improve strategic decision making by bringing the discipline of financial markets into qualitative strategic planning tools, and also by incorporating strategic realities into traditional capital budgeting models that do not explicitly account for the value of flexibility and managerial discretion (Trigeorgis, 1996; Amram & Kulatilaka, 1999). While effective implementation of real options analysis for resource allocation needs to overcome organizational and other challenges, real options theory holds out the promise of integrating strategic and financial analyses for corporate strategy (Bettis, 1983; Myers, 1984).

OVERVIEW OF THE VOLUME

The above three reasons why real options theory has become important for strategic management also correspond to three major streams of real options research in strategic management, which we label as real options investment decisions, implementation of real options, and performance outcomes of real options, as summarized in Fig. 1. Below we outline the three streams of research, and we use this framework to structure the chapters in this volume and highlight their contributions.

Before discussing the individual chapters that make up this volume, it is fitting to describe the development of this collection as well as offer our thanks to several people and institutions, without whose support this project would not have been possible. In late 2004, we identified scholars doing research on the above three topics and invited them to contribute original research papers to a volume devoted to real options in the *Advances in Strategic Management* series. In June of 2006, roughly forty authors and participants gathered at the Kenan-Flagler Business School at the University of North Carolina for a conference intended to help the authors develop their papers as well as prompt discussion and debate on real options theory in strategy. Also for these purposes, we invited several scholars doing research in different streams within strategic management to serve as session facilitators to exchange ideas about the future of real options. We owe a special thanks to those who served as facilitators for the various sessions at the conference: Gautam Ahuja (University of Michigan), Connie Helfat (Dartmouth College), Don Lessard (MIT), and Arvids Ziedonis (University of Michigan). We also are grateful for the assistance provided by staff members and doctoral students at UNC throughout this project. Finally, we

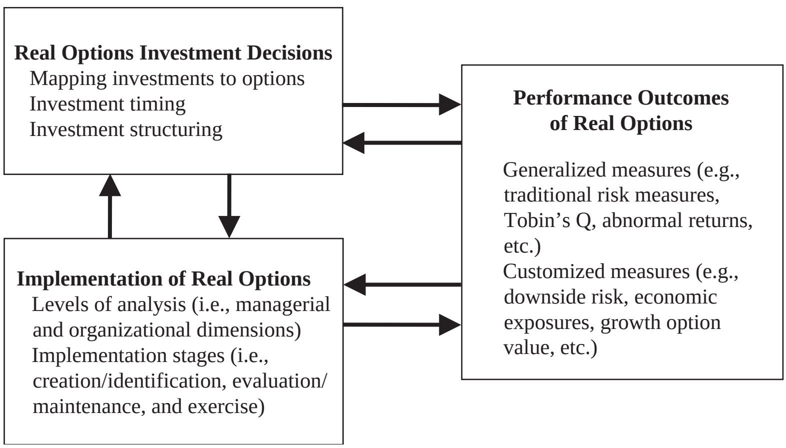

Fig. 1. A Framework for Real Options Research in Strategic Management.

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Advances in Real Options Research in Strategy

We begin this volume with a section including four chapters that delineate the recent advances in real options research in strategy, given that little work has systematically reviewed and analyzed existing contributions in the field. The first chapter by Li, James, Madhavan, and Mahoney reviews key applications of real options theory in strategic management and proposes several areas for future research. Their review suggests that real options theory provides unique insights into firms' investment under uncertainty; in particular, the theory has thrown new light on two topics of significant interest to strategy researchers: investment and divestment, and organization and governance. The review also indicates that real options embedded in strategic investments are valuable and have important performance implications for the firm. Their work concludes that real options theory has the potential to develop into an emerging, dominant conceptual lens in strategic management. The next chapter by Li provides a systematic analysis of the theoretical and empirical contributions of real options theory within international strategy. Her analysis builds on a framework that overlays three critical topics of research in international strategy (multinationality, market entry mode, and market entry timing) with three major approaches used in existing real options research in the field (real options modeling, real options reasoning, and empirical testing). She also outlines potential contributions that real options theory could make to two major streams of research in international strategy: research on transaction costs economics and research on internationalization theory. The third chapter, by Cuypers and Martin, focuses on real options theory's applications in research on joint ventures, a particular investment and governance mode that has drawn a substantial amount of attention in the strategy field. Their synthesis of the real options literature on JVs highlights real options theory's connections with several alternative theories on JVs, and they also examine how various options can affect a JV's development within and across different stages of the venture's life cycle. The final chapter in this section by Reuer and Tong categorizes and critiques the empirical research strategies that have been used to test real options theory in strategic management. Their research discusses studies that examine the timing and structuring of firm's investments, and their particular focus is on studies that examine the performance implications of firms' real options investments. Their analysis suggests that considerable evidence has accumulated for real options theory, and they also indicate the need to pay attention to the costs associated with real options within distinct investment stages as well as across different stages.

The chapters in this section suggest that real options theory is well suited for studying strategic decision making under uncertainty in various investment contexts, and they also call for more theoretical and empirical work that can help advance the theory in several concrete ways. In particular, there is a need to better articulate real options theory's link to other theories in the field and to specify the theory's appropriate boundaries. In addition, more and stronger tests are also required to fill the gap that still exists between theory and practice as well as to resolve some empirical inconsistencies documented in the literature. To better understand real options theory's applicability, researchers can extend the theory to new application areas, study several types of options that have received relatively less attention as well as option interactions, and pay more attention to the implementation aspect of real options.

Real Options and Strategic Investment Decisions

The second section focuses on firms' strategic investment decisions using real options theory. Research in this stream often starts by identifying different types of real options embedded in strategic investments. This research then examines how the presence or absence of these options may affect the timing and structuring of such investments under uncertainty and other environmental conditions. Research on the timing of investments has developed models to derive the optimal conditions under which firms are making investments (e.g., Kulatilaka & Perotti, 1998; Leiblein & Ziedonis, this volume; Lin & Kulatilaka, this volume) and has empirically tested whether the actual investment timing is consistent with real options theory's predictions (e.g., Kogut, 1991; Campa, 1994; Folta & O'Brien, 2004; Folta & O'Brien, this volume; Nerkar, Paruchuri, & Khaire, this volume).

The chapters in this section contribute to existing research on the timing of investments in several ways. The first chapter by Lin and Kulatilaka extends previous theoretical research by considering firms' investment decision in a specific industry setting, network industries, where strategic advantages arising from early commitment generate a valuable strategic growth option. Their study suggests that under high uncertainty, the strategic growth option often dominates the deferral option, thus reducing firms' investment thresholds and encouraging investments; in addition, the intensity of network effects enhances the value of the strategic growth option. The chapter by Folta and O'Brien examines the likelihood of firms making acquisition investments, which have embedded growth options and deferral options. They use a novel technique to isolate real options' effects on firms' investment thresholds, and they find that firms' thresholds affect the likelihood of acquisition in ways consistent with the theory's predictions. The chapter by Leiblein and Ziedonis applies real options theory to study firms' technological adoption strategies when there are multiple generations of technologies that are introduced successively. Their conceptual model identifies several conditions that differentially affect the value of deferral and growth options embedded in technological adoption, which in turn determines firms' optimal adoption strategy under those conditions. The chapter by Nerkar, Paruchuri, and Khaire extends recent research that views patents as real options, and they suggest that patents provide their holders with the right but not the obligation to sue potential infringers. They study the exercise of the option to sue in a novel setting – business method patents – and their findings suggest that the likelihood of a patent being litigated is positively associated with the value of the patent and the extent of disclosure in the patent.

Research on the structuring of investment has tended to focus on how firms structure their investments, such as the design of investment patterns and investment portfolios (e.g., Kogut, 1983; Hurry et al., 1992; Vassolo, Anand, & Folta, 2004; Anand, Oriani, & Vassolo, this volume). Research in this stream has also examined organizational governance and investment mode choice, such as alliances versus acquisitions (e.g., Chi & McGuire, 1996; Folta, 1998), assuming that a broader corporate investment decision is in place. The chapter by Anand, Oriani, and Vassolo in this section analyzes several factors that determine the value of a portfolio of real options and therefore can affect the composition of an option portfolio. Their core idea is that building an effective option portfolio requires attention to balancing growth and switching options, and they discuss how the value of an option portfolio depends on the width of the portfolio as well as the correlation among the underlying assets for each option. Their research thus also has useful implications for the implementation of real options, which is the focus of the four chapters in the next section.

Organizational and Managerial Dimensions of Real Options

Researchers have moved beyond strategic investment decisions to examine the implementation of real options in real organizations. While as a theory of investment, real options theory does not speak directly to managerial and organizational capabilities required for implementation, more research in this area can help to specify the theory's boundaries and enhance its managerial relevance. Most of the existing research in this area is conceptual in nature, describing various opportunities and challenges facing firms implementing real options. While specific topics vary, this research has tended to emphasize the importance of managerial or organizational dimensions during the various stages of option implementation, such as option creation and identification, option evaluation and maintenance, and option exercise.

Managerial and organizational factors can affect option implementation at different investment stages. For example, management processes and organizational structures can influence firms' identification of real options and their investments in real options (e.g., Kogut, 1985; Bowman & Hurry, 1993). The first chapter in this section, by Maritan and Alessandri, uses a capabilities perspective to link investments in real options to firms' resource allocation process. They first identify four components of the returns to an investment, deriving from industry-specific elements, as well as option and non-option elements, and they link these components to specific levers of the resource allocation process. They also suggest that research focus on the organizational and managerial aspects of the investment process from option creation to option exercise. This suggestion is consistent with the broader view that the evaluation, maintenance, and exercise of real options may need to deal with various management and organizational challenges (e.g., Kogut & Kulatilaka, 1994a, 1994b; Coff & Laverty, 2001; Adner & Levinthal, 2004). The following two chapters in this section further extend this view. Coff and Laverty suggest that managing real options in different organizational forms can incur different organizational costs, and therefore the organizational form that an option takes can have a profound effect on option exercise decisions. Their research also prescribes several organizational and management processes that may facilitate the management of real options in organizations and thus help to achieve real options theory's promise in strategic management. Adner recasts recent discussions on the appropriate applicability of real options theory to strategic management in terms of the characteristics of the resource reallocation process in organizations. His research considers some managerial and organizational drivers of mismatches between initial resource allocation logics and subsequent resource reallocation realities, and it highlights the need for a better understanding of the resource reallocation process in order to improve the appropriate usage of real options logic in organizations. In contrast to these chapters focusing on the challenges surrounding option implementation at different stages, the final chapter in this section, by Fister and Seth, analyzes one specific management challenge – how to encourage employees' investment in firm-specific human capital – using real options theory. Their application of real options theory points to several conditions that would lead to the use of certain contractual mechanisms to encourage such investment, and they discuss how various mechanisms might serve such a purpose through their impact on the value of the various options embedded in employment relationships.

Performance Implications of Real Options

The final section of the volume relates to an emerging stream of research that empirically investigates the performance implications of real options. As observed in Reuer and Tong (this volume), research within this stream has used both so-called generalized measures and customized measures to study the firm outcomes of real options investments. Generalized measures refer to market returns, market values, traditional risk measures, as well as other proxies that have also been used for testing other theories. Customized measures, in contrast, are specifically geared toward testing the unique payoff structure associated with particular real options, and the existing research has used such measures as downside risk, growth option value, abandonment option value, asymmetric exposures to uncertainties, and so forth.

The first chapter in this section by Chi and Levitas conceptualizes patents as technology options and empirically examines the option value of a firm's patent portfolios. Their research isolates the real options' effects by considering factors that tend to influence option value but not cash flow value. They do so by investigating how flexibility in excising options embedded in patents (proxied by citation dispersion) may moderate the effect of patent citations on the firm's market value, based on a theorem that is developed in Merton (1973) and also discussed by Bowman and Hurry (1993). The findings show that patent citations have a more positive influence on firm value when the citations are more dispersed and when there is a higher level of uncertainty, both of which are consistent with real options theory. The chapter by Oriani examines the value of a specific real option, i.e., technology switching option, which allows a firm to exchange an existing technology with a new technology. Specifically, he develops a model of the market value of the firm that explicitly incorporates a technology switching option, and he empirically tests the impact of this option on firms' value. His findings suggest that the technology switching option is valuable and that its value is enhanced for firms having a higher probability to exercise the option. The following chapter, by Alessandri, Lander, and Bettis, also empirically values specific real options, in this case corporate growth options. Their research builds on Kester's (1984) initial contribution to estimate a firms' value of growth options, using different valuation models that represent different assumptions and techniques. Their findings indicate that a firm's growth option value is a function of the macroeconomic and industry environment in which the firm operates, as well as firm-specific factors, suggesting the need for finer-grained study of real options at different levels of analyses. The final chapter in this section, by Guler, takes a different, yet complementary approach to studying the performance implications of real options. Her research investigates venture capitalists' investment policies in managing their portfolio companies, which are considered real options investments. Her findings indicate that firms differ in their capabilities to manage unsuccessful projects but not successful projects, reflecting earlier research's suggestion to focus on firm heterogeneity in studying the performance implications of real options.

FUNDAMENTAL QUESTIONS FOR REAL OPTIONS RESEARCH IN STRATEGIC MANAGEMENT

The set of chapters in this volume, combined with previous research, illustrate the increasing interest in real options theory in the strategy field. This work also demonstrates the rich theoretical content and wide empirical application of real options theory within strategic management. At the same time, real options theory is still at a relatively early stage of development, and many important issues will need to be tackled if the theory is to attain a status comparable to a number of other perspectives in currency in strategy research.

As an initial step in identifying and cataloguing some of the most pressing areas for research, we asked all of the participants at the conference to flag one or two key issues worthy of future research. Rather than simply listing these research topics, we attempted to distill them into a smaller number of fundamental questions that scholars need to address. During this process, we were mindful of Rumelt et al.'s (1994) proposal of four fundamental questions in strategy to differentiate this field of inquiry. We offer these questions to highlight some issues that are fundamental to real options research in strategy, in order for the theory to obtain the promise that researchers have envisioned for it (Bowman & Hurry, 1993; Kogut & Kulatilaka, 2001; Barney, 2002; Mahoney, 2005). As fundamental questions, they may challenge the current state of knowledge, yet we also believe that efforts to work on these questions can not only help real options theory make greater contributions to the strategic management field, but they can also bring into focus the distinctive contributions that strategy research can make to real options theory. Below we discuss the four questions and we include some additional questions under each broader category.

How can Real Options Theory Address the Foundations of Strategy?

The field of strategic management is concerned with the firm's strategic choices and directions, which can have an enormous influence on organizational performance. In its most strict form, real options theory can help parameterize sources of uncertainty and attach values to the various options embedded in the firm's strategic decisions and investment choices. At a broader level and used in metaphoric terms, real options theory can offer a more positive view of uncertainty and a more constructive view of managerial discretion by advising firms to attend to key value drivers for the various options embedded in strategic choices.

Strategy is also fundamentally interested in the heterogeneity in firm behaviors and performance outcomes. Like some other theories within organizational economics, real options theory does not seek to address firm heterogeneity directly. However, there are significant opportunities to enhance the conversation between real options theory and firm heterogeneity. For example, firms must engage in strategic investments to build or acquire resources and capabilities under considerable uncertainty and ambiguity (Lippman & Rumelt, 1982; Barney, 1986; Dierickx & Cool, 1989). As one fundamental theory to aid in investment decision making (Dixit & Pindyck, 1994), real options theory can enhance our understanding of why firms may differ by modeling firm's investments in a more analytic way (e.g., Pacheco-de-Almeida & Zemsky, 2003). Indeed, research has suggested that firms can use real options theory to guide their investments to build heterogeneous resources and capabilities (Baldwin & Clark, 1992, 2000). Firm heterogeneity can also be used to explain particular predictions of real options theory (Tong & Reuer, 2006). For instance, firm heterogeneity and the associated asymmetric expectations across firms may lie at the heart of the reason why firms may exhibit different investment behaviors when facing the same uncertainty, whether the investments are made for strategic factors, real options, or financial securities (Barney, 1986; Chi & McGuire, 1996; Hull, 2003).

The following subquestions connect to this broader question, which is of particular interest to strategic management:

- How can real options theory explain competitive advantage? How can firms facing the same options achieve differential performance? If firms face different options and this creates heterogeneity in resources and performance, what is the source of the firm heterogeneity in the first place?
- How can real options theory speak to corporate strategy? What are the implications of viewing the firm as a portfolio of options rather than a bundle of resources and capabilities? How can research use real options theory to explicate the development of core competencies?
- How important are the option properties of organizational governance structures in explaining boundary of the firm choices?

How can Real Options Theory Connect to Other Theories in Strategy?

The distinctiveness of real options theory for strategic investment decisions compared to other theories has been discussed in a previous section, and its uniqueness also explains strategy researchers' initial enthusiasm for the theory. Real options research clearly should continue to highlight the theory's unique aspects as a standalone theory, by further examining the critical questions and predictions the theory poses and by emphasizing the theory's unique constructs as well as the links between these constructs and strategic decisions or organizational performance. Equally important, conceptual and empirical research should work to tease apart the theory's predictions from those of rival theories and better identify real option theory's boundaries in strategic management.

Another way to advance strategy research on real options is to combine the theory with other theories to examine particular questions or phenomena. Such an integrated approach has the potential advantage of offering a more complete understanding of the questions examined, and recent research has made headway in this direction. For example, strategy research has combined real options theory and transaction cost economics to explicate the conditions under which firms may invest in JVs and has considered related alliance design issues (e.g., Chi & McGuire, 1996). Connecting real options analysis with the resource-based view has the potential to improve the analysis of firms' corporate development trajectories such as the directions and patterns of diversification (e.g., Kim & Kogut, 1996; Matsusaka, 2001; Bernardo & Chowdhry, 2002). Incorporating the resource-based view and related notions of firm heterogeneity also holds the potential to explain the heterogeneous expectations and investment behaviors of firms facing the same external uncertainty (e.g., Tong & Reuer, 2006). In addition, integrating real options theory with other theories of organizational governance can better inform corporate strategy decisions such as make or buy decisions and the firm's vertical boundaries (e.g., Leiblein & Miller, 2003). Ample opportunities also exist for extending real options theory into contexts with agency problems, competitive rivalry, or other sources of endogenous uncertainty, and strategy research has barely started to consider real options theory in tandem with agency theory, game theory, or organizational learning theory.

Clearly, both of the two approaches are valuable and can be appropriate in different research designs, yet they also present some additional questions for scholars to consider when framing their research and designing studies on real options:

- In general, what is the best way forward for real options theory to make greater contributions to strategy research, as a standalone theory or as a theory integrated with others?
- More specifically, how should research implement each of the two approaches? What are some of characteristics of the questions to which real options theory should be applied? What phenomena can real options theory potentially explain better than other theories? What are the most interesting empirical horse races to be run?
- What other theories can be profitably combined with real options theory, and in what contexts? How can the boundaries between the theories be delineated carefully while also acknowledging shared concerns and points of connection?

How Important is Formalism in Real Options Theory?

Real options theory has been applied in strategy research in many different ways, yet in a certain sense, studies using the theory might be arrayed along a continuum ranging from very formal work to metaphoric applications. At one extreme, formalism can help identify the workings of real options, isolate the embedded options, and pin down the option value drivers, yet important strategic realities may need to be assumed away or differences in assumptions in financial and strategic domains glossed over. At the other extreme, metaphoric usage of real options might better attend to strategic or organizational realities and broaden the applications to which option theory might speak, yet it may not reflect concerns or variables directly featured in formal models of real options. Therefore, the question is: how important is formalism in the use of real options theory in strategic management? In this connection, it is worth noting that such a question is useful to ask not just for a particular theory such as real options, but the question also has great applicability to other theories within the strategy field. The advancement of a good theory often needs to attend to such conflicting considerations.

Formalism need not be equivalent to an exclusive focus on option valuation models per se, however. For strategy research, what appears to be more important is to determine what questions to investigate that are core and interesting to our field of inquiry, whether using analytic or empirical models to evaluate investments or strategic choices in a rigorous fashion. Metaphorical usage of real options also can be valuable for certain applications. For example, research has suggested that corporate managers more often use real options theory as a framing device or decision framework rather than as a formal valuation tool, yet such practices have been powerful and have also in many ways transformed managers' and investors' views on strategic investments such as R&D, information technology, and other platform investments (Triantis, 2005). Clearly, the challenge for research is to determine the proper balance between formalism and metaphoric usage of the theory so that applications of real options are still sound and sensitive to alternative explanations. While research needs to consider the kind of topics and contexts for real options as well as weigh the level of maturity achieved and knowledge accumulated, the following subsidiary questions also might be considered:

- When should real options theory be used as an analytic tool versus a heuristic? How can research establish a strong connection to the features in formal models in using real options theory as a heuristic?
- How can strategic and organizational realities be incorporated into analytical models of real options? How can real options be modeled more explicitly and precisely in order to link theory with empirics more tightly?
- What is the best way to determine the real options characteristics in various assets and investments? When does it pay to designate a strategic choice or investment as an option?

What is the Role of Management and Organization in Real Options Theory?

To the extent that the trading of options on financial assets with posted prices may still be subject to inefficiencies, great frictions must exist in the acquisition of real options on strategic assets in factor markets as well as in the development of such strategic options within organizations. For example, organizations are run by boundedly rational managers with their own cognitive limitations and behavioral biases, and they may have limited attention and may face difficulties in recognizing complex cues accompanying multiple sources of uncertainty (Kogut, 1991; Miller & Shapira, 2004; Barnett, 2005). In addition, organizations may not have the appropriate structures or supportive systems in place (Kogut, 1985; Coff & Laverty, 2001), and managers might also misuse their discretion and deviate from optimal decision criteria as a consequence (Trigeorgis, 1996; McGrath, Ferrier, & Mendelow, 2004). Real options theory is a theory of investment decision making that places a high demand on managerial and organizational capabilities for execution. Despite the soundness of the theory, any of the factors above can threaten to destroy option value at various stages of option implementation (e.g., recognition, creation, maintenance, exercise, etc.).

Viewed from another perspective, however, to the extent that managers and firms factor these considerations into their decision calculus and develop corrective mechanisms, they can help contribute to option value creation. Indeed, the existence of frictions in the process of the development and exchange of real options has helped open up an important opportunity for strategic management research to make significant contributions to real options theory. One of strategic management's distinctive competences is to provide a holistic view of the firm by bridging strategy formulation to management and organization. Employing this distinctive competence, strategic management research can tackle important questions at the heart of the successful implementation of real options, and such work will advance both the theory as well as its practice, which research in other fields will find hard to achieve (e.g., Hartmann & Hassan, 2006). Toward this end, the following subquestions are put forth:

- How do specific management and organizational factors matter for real options? How does the importance of management and organization vary across firms and strategic contexts?
- How do firms actually implement real options analysis? How do managers perceive various sources of uncertainty and apply real options analysis or reasoning in *ex ante* strategic decision making processes?

- What challenges in other option investment stages (e.g., recognition, creation, and maintenance) should we devote more attention to, in addition to challenges surrounding option exercise? How should firms measure and reward the creation, maintenance, and exercise of options in organizations, especially when some managers develop assets and others operate them?

Clearly, the four questions are not isolated, and they connect to one another to address some common themes or broader concerns. For example, the first two questions primarily focus on how real options theory can better contribute to strategy research, and the latter two turn to ask how strategic management can make significant contributions to real options theory. Also, these questions are likely not collectively exhaustive, and other useful questions can certainly be suggested; nevertheless, we believe that most of them can be related to the four questions here in one way or another. These four questions are therefore fundamental to our understanding of real options theory in strategic management and key to future progress of research in this area.

This volume illustrates how real options theory has significantly contributed to strategic management research, as well as how scholars in strategic management are uniquely positioned to advance the theory. The chapters demonstrate the diverse applications of real options theory in strategy, and they also point to a range of methodologies and analytical lenses that future strategy research could leverage to improve existing understanding of the theory. The volume and the conference have also identified several pathways for real options research to advance and develop into a major theoretical perspective in the field. Our hope is that this volume can serve as a useful guide to real options research in strategic management for interested readers, and as a catalyst for additional research on this theory in coming years.

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PART II: ADVANCES IN REAL OPTIONS RESEARCH IN STRATEGY

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REAL OPTIONS: TAKING STOCK AND LOOKING AHEAD

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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.

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

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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, 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, & 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 & Routledge, 2002), transaction costs (Chi & McGuire, 1996), resources, capabilities and learning (Bernardo & Chowdhry, 2002; Childs & Triantis, 1999; Vassolo, Anand, & Folta, 2004), and game-theoretic aspects of investment (Grenadier, 2000; Smit & Ankum, 1993; Smit & 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

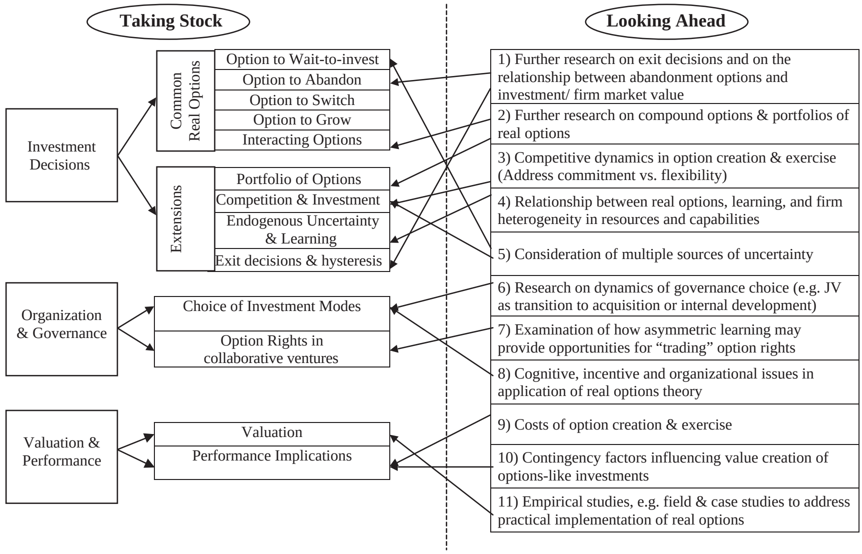

Fig. 1. Taking Stock and Looking Ahead: A Reader's Roadmap.

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. Fig. 1 provides a roadmap of the key sections and major takeaways.

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.

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

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, p. 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, & 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 & 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 & 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, & 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 U.S. 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 & 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, & Swary, 1996; Myers & 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 & Pindyck, 1995). This positive effect of the abandonment/switching option on investment propensity is particularly important to investment decisions concerning multi-stage projects (Chi & 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 & Pindyck, 1994; Rivoli & 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 (JV), 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 JV acquisitions. Similarly, Folta and Miller (2002) show that managers acquire additional equity stakes of a 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 & 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 & 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 U.S. 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 & 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 et al. (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 et al. (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 proprietary[1]) (Kester, 1984; Smit & Ankum, 1993). It will also weigh between commitment value from preemption or early mover advantages and flexibility value from real options in investment projects (Smit & 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 & 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 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 & 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 & 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 & 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 & 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 & 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 also 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 'proprietariness' 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, & 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 & 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 & 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, Bragger, Hantula, and Kirnan (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, & 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 & 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 JVs), 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 remain 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 & McGuire, 1996). Since Kogut (1991), it has been held that the 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 JV.

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 not only incur greater short-term marginal production costs than integration but may also 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 & 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 & 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 & Seth, 2004) or over the behavioral tendencies of partners in a world of information asymmetry and opportunism (Chi & 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, & 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 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 IJV transactions from 36 different host countries and a U.S. 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 Laamanen (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 & Moskowitz, 2001; Lander & 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 & 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 & 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 et al. (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 & Kulatilaka, 1994a). Miller and Reuer (1998a) find from cross-sectional analyses that foreign direct investment (FDI) 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 & Pindyck, 1994; Kogut & 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 the 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 & 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 have emerged since the 1990s (e.g., Grenadier, 2000; Smit & 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, which 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 & O’Brien, 2004) as well as the interaction between option-like projects (e.g., MacMillan & 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 & 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 & 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 & O'Brien, 2004), squared residuals or standard error of regression (e.g., Favero et al., 1994; Hurn & 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 FDIs reducing exposures to exchange rate volatility and firms managing exchange rate exposures asymmetrically, Reuer and Leiblein (2000) do 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 & 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 & O'Brien, 2004), equity joint ventures (e.g., Chi & McGuire, 1996; Kogut, 1991; Reuer & Leiblein, 2000), foreign entry and multinational operations (e.g., Allen & Pantzalis, 1996; Campa, 1994; Miller & Reuer, 1998b; Rangan, 1998; Rivoli & Salorio, 1996), R&D/patenting decisions (McGrath, 1997; McGrath & Nerkar, 2004), and corporate growth value (e.g., Tong et al., forthcoming). Other applications may include venture capital and entrepreneurship, which involve both 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 & Moskowitz, 2001; McGrath, 2001). Accordingly, real options theory can become an important theoretical perspective towards venture capital and entrepreneurship (Hurry, Miller, & 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 & Moskowitz, 2001; Lander & 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 & Moskowitz, 2001; Lander & 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 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 & 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 & 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 & 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 & Levinthal, 2004).

Concerning organizational pre-requisites to successful real options strategies, Amram and Kulatilaka (1999, pp. 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 & Levinthal, 2004; Coff & Laverty, 2001; Garud, Kumaraswamy, & Nayyar, 1998; Miller & 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.

NOTES

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).
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.

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REAL OPTIONS THEORY AND INTERNATIONAL STRATEGY: A CRITICAL REVIEW

Jing Li

ABSTRACT

The application of real options theory to international strategy has surged in recent years. However, it is still a relatively new and loosely defined field, and there are several constraints on practical applications of this powerful theory. To move forward this field, the paper first provides a systematic analysis of theoretical and empirical contributions of real options theory to three critical issues in international strategy: (1) valuing multinational networks, (2) assessing market entry modes, and (3) evaluating market entry timing. The paper further suggests that future studies can focus on a refined treatment of uncertainty and the development of a dynamic theory in international strategy. Five testable propositions are developed in these directions.

INTRODUCTION

Many early applications of real options theory to strategy have been motivated by various phenomena in international business (Dixit, 1989; Kogut, 1983). Recent years have also seen an increasing academic interest in the

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intersection of real options theory and international strategy (Chi & McGuire, 1996; Tong, Reuer, & Peng, 2007). Despite all that, applying real options theory to international strategy is still a relatively new and loosely defined field. Additionally, there are real constraints that have limited theoretical and practical applications of this powerful theory. Real options theory is complex as it draws on diverse fields of economics, finance, and strategy. Also, the rapid advances in the modeling and solution techniques are too diverse to be easily brought to the attention of a researcher in international strategy. However, real options theory presents a very high potential to address some of the most perplexing questions in the field. This suggests that a critical assessment of this field is particularly important and timely. This paper presents a critical review of the real options approach in international strategy, assesses theoretical and empirical contributions in this area, and provides some broad directions for future research.

It has been recognized in international business that uncertainty, which often exposes multinational enterprises (MNEs) to unfavorable conditions or potential opportunities, plays an important role. These challenges and opportunities in the international environment necessitate a theory, which helps to analyze MNEs' strategies under uncertainty. For example, how can MNEs utilize their multinational networks to deal with uncertainty? How can MNEs make sensible sequential market entry decisions (mode and timing) to benefit from uncertainty? The classical theories in international business, such as internalization theory (Buckley & Casson, 1976) and the Ownership-Location-Internalization (OLI) model (Dunning, 1980), do not explicitly consider the role of uncertainty in multinationals' strategic decision making. Further applications of transaction cost economics have dealt with uncertainty but mainly view uncertainty as something associated with transaction costs which should be minimized (Anderson & Gatignon, 1986). Applications of real options theory to international strategy, however, have recognized that uncertainty is not only associated with downside risks but also with potential opportunities that MNEs can take advantage of (Chi & McGuire, 1996; Tong & Reuer, 2007). To strategically benefit from uncertainty, MNEs should create real options (such as the option to defer and the option to grow) to maintain flexibility in adjusting decisions in response to new opportunities or challenges (Kogut & Kulatilaka, 1994). Real options theory, which effectively conceptualizes and quantifies the value of real options, can contribute to the development of theories in MNEs' strategic decision making under uncertainty.

Table 1 lists some of the key articles that take a real options approach in international strategy, strategy with no international focus, and economics.

Table 1. Influence of Key Real Options Papers on International Strategy[a].

Papers	Times Cited	Times Cited by Papers with a Focus on International Strategy
Dixit (1989)	282	31
Kogut (1991)	161	45
Kogut and Kulatilaka (1994)	107	76
McGrath (1997)	73	3
Buckley and Casson (1998)	45	22
Campa (1993)	25	23
Rivoli and Salorio (1996)	23	21
Reuer and Leiblein (2000)	21	9
Chi and McGuire (1996)	18	11
Allen and Pantzalis (1996)	14	13
Rangan (1998)	13	13
Miller and Reuer (1998a)	9	6
Tang and Tikoo (1999)	7	5
Campa (1994)	6	4
Kouvelis et al. (2001)	5	5

[a]These citations are obtained from the Social Science Citation Index on November 15, 2006. I read the title and abstract of each paper to identify whether each paper focuses on topics in international strategy.

It also reports the total number of citations for each article and the number of citations by papers with an international focus. The overall limited number of citations with an international focus indicates that real options theory may have achieved only limited influence on research in international strategy, even though real options theory has substantial potential to improve our understanding of uncertainty, flexibility, and international strategy.

To move forward this field, this paper intends to present the value of a real options approach to topics in an international context. Specifically, I begin by clarifying the definition of real options and real options theory. I then discuss the unique benefits of using real options theory in international strategy as well as summarize and critique the recent applications of real options theory. Primarily, real options theory has been adopted to analyze three subjects: (1) the operating flexibility of MNEs' networks of subsidiaries, (2) advantages of using international joint ventures to enter a market, and (3) optimal investment timing decisions. The theoretical treatment of real options has used two closely related but distinct approaches: (1) real options reasoning and (2) real options modeling, and several empirical studies have tested some of the implications from a real options approach. Finally, I highlight how researchers in international strategy can leverage the potential of real options theory for a refined treatment of uncertainty and for the development of a dynamic theory. Five testable propositions are presented regarding the relationships between uncertainty and strategic decision making.

REAL OPTIONS AND REAL OPTIONS THEORY

Definition of Real Options

The concept of real options originates from financial options (Myers, 1977). Financial options afford option holders the right but not the obligation to sell or buy stocks at a predetermined price called the exercise price for a predetermined period of time. Hence, financial options allow option holders to pursue opportunities that have significant upside potential while containing downside risks, making financial options possess an asymmetrical performance distribution. Such asymmetry, derived from having the right but not the obligation to exercise the option, lies at the heart of the option's value (Amram & Kulatilaka, 1999; Trigeorgis, 1996).

Myers (1977) first recognized that characteristics of capital investments are analogous to financial options; current sunk investments create real options because they provide future discretionary opportunities. Bowman and Hurry (1993) further argued that an organization's resources – its capabilities and assets – can be viewed as a bundle of real options for future strategic choice. Following the concepts in Myers (1977) and Bowman and Hurry (1993), I have the following definition of real options in international strategy: Making an international investment creates real options when managers in MNEs obtain the right but not the obligation to take a future action (e.g., deferring, expanding, contracting, or abandoning).

Two characteristics are required to determine whether a strategic investment in a project provides real options: first, there is volatility regarding future payoffs of the project; second, there is managerial flexibility in increasing commitment or controlling losses according to the resolution of uncertainty in the business environment. Note that managerial flexibility reflects managers' active rather than passive management activities. For example, an MNE can benefit from its worldwide business network in terms of switching locations of production in response to exchange rate volatility (Kogut & Kulatilaka, 1994). Such active management is different from the pure geographical diversification (e.g., Rugman, 1976), which plays a passive role in reducing variance of investment portfolios. Multi-staged investment projects, such as investments in new capacity, geographical expansion, and research and development, satisfy both criteria and provide real options (Copeland & Antikarov, 2001; Li, James, Madhavan, & Mahoney, 2007).

Real options differ from financial options on several characteristics. As summarized in Table 2, real options are based on real assets and are often non-tradable, and their value is influenced by managerial actions. Often, these are not included in formal contracts but are implicitly embedded in strategic investments (Buckley, Casson, & Gulamhussen, 2002). The rules for exercising real options are often not as clear as those for financial options (Adner & Levinthal, 2004).

There are different types of real options in international strategy. Table 3 lists five types of real options that are frequently observed in international strategy: the option to defer, the option to grow, the option to switch, the option to abandon, and the option to learn. Examples are also provided in Table 3. These options are particularly important in decisions such as market entry timing, market entry modes, and choice of a multinational network.

Real Options Theory

Real options theory provides a systematic tool to conceptualize and quantify the factors that contribute to the value of real options, which facilitates firms' decision making under uncertainty. We can understand real options theory from two perspectives: real options reasoning and real options modeling.[1] The former approach favors qualitative applications of option-pricing models over quantitative valuation and helps to recognize the importance of having managerial flexibility and the value of real options from active management. The latter approach refers to the combination of option-pricing models with economic models such as those in game theory (e.g., Chi, 2000; Kulatilaka & Perotti, 1998) to prescribe thorough forward-looking quantitative analysis to guide investment decisions.

Real Options Reasoning

Real options reasoning captures the strategic value of managerial flexibility in a way that many managers have intuitively been evaluating it (Folta & O'Brien, 2004). Real options reasoning is appropriate when factors that influence the option value of an investment can be clearly identified and

Table 2. Differences between Real Options and Financial Options.

	Financial Options	Real Options
Types of assets	Financial options are based on monetary assets. Financial options are tradable.	Real options are based on real assets. Real options (other than commodity or equity options) are often non-tradable as they are asset specific to the firm or organization (Buckley et al., 2002).
Influence of managerial actions	Holders of financial options have no influence over the value of financial options.	Managerial actions can influence a variety of aspects of the value of real options, such as the NPV of underlying assets or volatility structure (Roberts & Weitzman, 1981). E.g., a company can come up with a new technology that raises the NPV of the underlying project, or it can pre-amplify investments to reduce some uncertainty it faces (McGrath, 1997).
Contracts	Financial options are embedded in formal contracts, which explicitly specify options' exercise prices and expiration dates.	Real options are often not included as a clause in formal contracts (e.g., joint ventures, see Reuer & Tong, 2005). Some real options are not even contractual at all (e.g., an MNE's decision to upsize, downsize, or relocate operations).
Realization of potential benefits from the exercise of options	Financial option holders can always realize potential gains when they choose to do so, due to specifications in the formal contracts.	Real option holders sometimes cannot realize potential benefits from exercising real options due to the lack of formal contracts. E.g., bargaining costs arising from negotiation of an acquisition price between joint venture partners might diminish any value from exercising the option (Chi, 2000).
Option exercising rules	Financial options have clear-cut exercising rules.	Real options sometimes do not have a clear set of exercising rules when these options are created. E.g., unexpected discoveries during the period between the initial investment and the prescheduled time of full investment change the optimal rules of exercising options (Adner & Levinthal, 2004; Zardkoohi, 2004).

Table 3. Types of Real Options in International Strategy.

Types of Real Options	Examples	Important in
Option to defer	A firm has the option to delay market entry facing high uncertainty in market demand.	Choice of market entry timing
Option to grow	A firm that enters the market through a joint venture has the option to acquire its partner's equity to expand in the future.	Choice of market entry mode
	A firm that enters the market at an early stage has the option to expand quickly and preempt market entry by competitors.	Choice of market entry timing
Option to switch	A firm has the option to switch raw materials and production across subsidiaries within a multinational network contingent on exchange rate volatility.	Choice of a multinational network
Option to abandon	A firm has the option to reduce commitment and withdraw from the market when market conditions in the foreign country are negative.	Choice of market entry mode
Option to learn	A firm has the option to learn from partners if they provide useful knowledge in joint ventures.	Choice of market entry mode

synthesized (e.g., McGrath, 1997). Most existing applications of real options theory to strategy use real options reasoning to identify the importance of keeping options open. In this approach, there are six factors that drive the value of a real option (Copeland & Antikarov, 2001, p. 7):

(1) An increase in the Net Present Value (NPV) of the underlying risky project on which a real option is based increases the value of a real option;
(2) An increase in the investment cost (the option exercise price) reduces the NPV of the underlying project and therefore the value of a real option;
(3) A longer time to expiration of a real option allows decision makers to learn more about the uncertainty and therefore increases the value of a real option;
(4) An increase in uncertainty regarding the payoffs of the underlying project increases the value of managerial flexibility and therefore the value of a real option;

(5) An increase in the risk-free interest rate increases the time value of deferring the investment cost and therefore increases the value of a real option; and
(6) An increase in cash flow lost to competitors decreases the value of a real option.

By carefully examining these six factors and their corresponding meanings in an international investment, we are able to apply real options theory to specific topics in international strategy.

Real Options Modeling

Real options modeling combines economic models with option-pricing solution techniques. Real options modeling is more appropriate than real options reasoning when (1) problems are new or complex (due to multiple sources of uncertainty or multiple stages of investment) and thus require well-specified economic models to systematically evaluate these problems and extract their most important aspect, and (2) option-pricing solution techniques are relied on to identify rigorously the evolution of uncertainty and to specify the relationship between parameters of interest and the valuation of real options. Real options modeling is also appropriate when testing from real data is not available. In these cases, establishing real options models and using simulation techniques can lead to meaningful empirical results. Real options modeling, as any economic modeling, can be viewed as a success when it is capable of drawing attention to phenomena that have not been noticed and integrating the explanation of these phenomena with explanations of already known phenomena (Buckley & Casson, 1998, p. 24). As solution techniques, option-pricing models are more advanced than the traditional NPV method and decision-tree analysis, because they are able to capture the value of managerial flexibility more accurately (Copeland & Antikarov, 2001, p. 87).

A good example of applications of real options modeling to international strategy is about the mode-switching decisions in international joint ventures (IJVs) by Chi and McGuire (1996). Evolution of an IJV depends on evaluation of the IJV by at least *two* partners, which often changes *over time*, thus making business expansion or contraction through ownership changes more complex decisions than those in wholly owned subsidiaries. In addition, it is difficult to obtain real data information on both sides of joint venture partners, as evidenced by the current empirical analyses of IJV ownership transitions that are usually based on the information of one partner. Chi and McGuire (1996) combined option pricing techniques from

Cox, Ross, and Rubinstein (1979) with economic models to illustrate the dynamics of each partner's valuation of the IJV and mode-switching decisions in the IJV. Using a simulation approach, the authors provide more insights on the dynamic development of an IJV than previous work.

APPLICATION OF REAL OPTIONS THEORY TO INTERNATIONAL STRATEGY

When entering an overseas market, MNEs are inevitably facing a variety of uncertainty. The increasingly integrated global economic environment implies that uncertainty the MNEs face is no longer confined to the markets where they have their operations and businesses (Buckley & Casson, 1998). Indeed, since international production became a feature of MNE operations, political, social, and economic disturbances in many countries could significantly affect global supplies of manufactured products.

In general, we can divide uncertainty into two types: exogenous and endogenous (Folta, 1998; Roberts & Weitzman, 1981). Exogenous uncertainty is not affected by a firm's actions and can only be revealed over time. Uncertainty in the macroeconomic environment (such as political and economic conditions) usually belongs to this type. Endogenous uncertainty can be decreased through investments by an individual firm. Uncertainty at the microeconomic environment (such as consumer needs and competition conditions) and at the firm level (such as relationships in partnerships) mainly belongs to this type. For example, an MNE can invest in an IJV to reduce uncertainty about the amount of complementary knowledge (e.g., distribution channels and relationships with the governments) that local partners can provide and the extent to which local partners may behave opportunistically by appropriating MNEs' advanced technology to their own advantages.

If investments could be fully recovered from the market, MNEs would have great flexibility in dealing with business shocks since they could correct the mistakes in their decision making at any moment. However, many investments are irreversible, and such irreversibility substantially limits managerial flexibility in dealing with uncertainty. The irreversibility of investments may be the result of several causes. First, according to transaction cost economics, investments are more likely to be irreversible if they are specific to a company or an industry because such asset specificity increases the difficulty in selling them in the market (Williamson, 1985). Moreover, such asset specificity increases the problem of information asymmetry in the used goods markets; buyers tend to lower their estimations of the quality of these assets and lower their willingness to pay for them (Akerlof, 1970). Additionally, irreversibility may be exacerbated by government regulation and institutional arrangements. For example, capital controls may make it impossible for foreign investors to sell assets and reallocate their funds (Pindyck, 1991).

Traditional theories in international business, such as internalization theory (Buckley & Casson, 1976; Rugman, 1981) and the OLI model (Dunning, 1980), have not fully considered the effect of uncertainty and the irreversibility of investments on MNEs' decision making.[2] For example, internalization theory suggests that the imperfections of intermediate product markets, particularly those of patented technology and human capital, provide an incentive for MNEs to internalize the knowledge market by building their wholly owned subsidiaries (WOSs) in foreign markets. However, building WOSs usually involves large irreversible investments. By committing to such investments, MNEs lose some flexibility in adjusting their decisions when more information becomes available and may face significant losses when the future is unfavorable. Thus, even though establishing WOSs is justified from the point of view of minimizing transaction costs, the advantages of such a decision may be reduced if we consider the dynamic environments of a firm's investment.

Although further applications of transaction cost economics to international investments have considered external and internal uncertainty and irreversibility of investments (e.g., Anderson & Gatignon, 1986), they do not consider any means to benefit from uncertainty. They, however, view uncertainty as a source of transaction costs, thus proposing to use high control mechanisms to minimize transaction costs. In other words, transaction cost economics does not fully recognize potential opportunities embedded in uncertainty or precisely value managerial flexibility in adjusting investment decisions in response to the revelation of uncertainty. Therefore, as elaborated later in this chapter, real options theory contributes to the field by introducing a new way of thinking, i.e., uncertainty implies risks as well as opportunities, and firms are able to benefit from uncertainty by creating real options to maintain flexibility in response to new information (Buckley & Casson, 1998; Rivoli & Salorio, 1996).

Moreover, since real options theory values managerial flexibility in response to new information, it has the potential to contribute to the development of theories in sequential decision making such as internationalization theory. Internationalization theory promotes incremental international expansions of firms (Johanson & Vahlne, 1977), but it is not entirely clear about the speed of the internationalization process. As specified later in the paper, real options theory can be formally incorporated into and enrich the

Table 4. Literature Review on Applications of Real Options Theory to International Strategy.

Research Subjects	Methodology		
	Real Options Reasoning	Real Options Modeling	Empirical Testing
Multinationality	1 Kogut (1983), Buckley and Casson (1998)	2 de Meza and van der Ploeg (1987), Kogut and Kulatilaka (1994), Huchzermeier and Cohen (1996), Dasu and Li (1997)	3 Rangan (1998), Allen and Pantzalis (1996), Tang and Tikoo (1999), Pantzalis (2001), Reuer and Leiblein (2000), Tong and Reuer (2007), Miller and Reuer (1998a, 1998b), Campa (1994)
Market entry modes	4 Buckley and Casson (1998)	5 Chi and McGuire (1996)	6 Reuer and Tong (2005), Tong et al. (2007), Kouvelis et al. (2001)
Market entry timing	7 Rivoli and Salorio (1996)	8 Dixit (1989)	9 Campa (1993)

study of the internationalization process (Seth & Chi, 2005). To sum up, it is necessary to introduce real options theory to research in international strategy as it can contribute to a refined treatment of uncertainty as well as the development of a dynamic theory in international strategy.

Table 4 categorizes the existing papers on international strategy that adopt a real options approach, according to their research subjects and methodology. Real options theory has been applied to three main research subjects: multinationality and operational flexibility, the advantages of using IJVs to enter a market, and the optimal timing of investment decisions. In terms of methodology, some papers employ real options reasoning for conceptual thinking, some build normative models by using option-pricing techniques and simulation, and others use quantitative data to test the implications of real options theory. The resulting 3×3 matrix produces nine research foci. We discuss the strengths and weaknesses of the research represented in each of the nine foci as follows.

Multinationality and Operational Flexibility

The first category of applications (Foci 1, 2, and 3) includes papers that take a real options approach to explain the relationship between multinationality, operational flexibility, and performance. These studies can shed light on the numerous empirical studies on multinationality and performance (e.g., Lu & Beamish, 2004). Articles based on real options reasoning and modeling indicate the following logical flow for the impact of multinationality on operational flexibility and performance: multinationality provides an MNE with the option to switch sourcing, production, or distribution within the network when the environment changes; the option to switch has a positive impact on the market valuation of an MNE and a negative effect on corporate risk and corporate exposure. However, empirical tests of the above ideas indicate mixed results: multinationality may increase market valuation and reduce corporate risks of MNEs but only under certain conditions.

Focus 1: Multinationality/Real Options Reasoning

Kogut (1983) first presented that the operational value of a global system lies in the unique ability of multinationals to reduce the costs of operating in an uncertain world. First, an MNE is able to exploit the conditions of uncertainty and of institutional environments by arbitraging institutional restrictions, e.g., tax codes, antitrust provisions, and financial limitations. For example, an MNE can choose in which country to declare its profits so as to minimize the tax burden. The second advantage of being multinational is the capture of externalities in information. The third advantage is about economies of scale in both marketing and manufacturing on a global scale. Therefore, national boundaries do not represent only the costs of tariffs and transport; they also represent profit opportunities which can only be exploited by an MNE (Kogut, 1983, p. 43). Hence, the evaluation of a multinational network should include the value of holding the options to switch production, distribution, and profits within the network.

Since a multinational network provides the option to switch, choice of location in a multinational network should be strategic in order to enhance an MNE's operational flexibility. Buckley and Casson (1998) provided an example to illustrate this idea. MNEs can choose a regional production and distribution hub, where several neighboring countries are serviced from the same location. Because the hub is nearer to each market than is the home location, it reduces transport costs and offers better local information. Meanwhile, because the hub is close to several markets, it avoids exclusive commitments to any one of them. Thus, if one of these markets declines, products can be switched to other markets. The option to switch enhances an MNE's operational flexibility while limiting its losses.

Focus 2: Multinationality/Real Options Modeling

Several studies have adopted real options modeling to analyze the value of operating flexibility provided by multinationality. For example, de Meza and van der Ploeg (1987) treated the cost structures in different locations as uncertain variables and showed that producing in various locations generates opportunities for firms to manufacture in the place with lowest costs and thus benefits an MNE, even if the MNE is risk-neutral, and the cost fluctuations in different locations are highly correlated.

To more accurately capture the value of an MNE as a network of subsidiaries, Kogut and Kulatilaka (1994) built a real options model to verify the idea that the value of the network lies in the opportunity to benefit from uncertainty through coordination of geographically dispersed subsidiaries. Based on the following assumptions: (1) an MNE has two subsidiaries located in different countries, (2) the MNE needs to minimize total production costs of the two subsidiaries, and (3) there is only one source of uncertainty – fluctuations in the exchange rate – Kogut and Kulatilaka (1994) developed a stochastic dynamic programming model in examining the option value of a multinational network in response to exchange rate shocks. They concluded that having the option to move production to a location with lower input prices helps the MNE to ensure against detrimental movements of the real exchange rate. This insurance feature of the value derived from location flexibility is greater in periods of increased volatility in exchange rates. Hence, the value of multinationality (network of subsidiaries) increases with greater volatility.

Similarly, Huchzermeier and Cohen (1996) used a multinomial approximation model to demonstrate that an MNE can alter product design and supply chain network design so as to mitigate the risks related to exchange rate volatility. Dasu and Li (1997) further studied the structure of the optimal policies for an MNE operating plants in different countries, that is, when and how much an MNE should alter production quantities in different locations, provided the relative costs of production among the plants vary due to external factors such as exchange rates and tariffs.

Focus 3: Multinationality/Empirical Testing

Both real options reasoning and modeling support the idea that multinationality improves operating flexibility. An implicit assumption is that MNEs can always realize such operating flexibility whenever opportunities arrive. However, there are counterarguments in organizational theories that multinationality may fail to improve operating flexibility. For example, MNEs' full-fledged foreign subsidiaries are also internal organizations in their own right and tend to protect their local resources and mandates rather than serve the interests of MNEs as a whole (Ghoshal & Nohria, 1989; Rangan, 1998). Moreover, even without concerns about subsidiaries' self-protection, we might still doubt how much flexibility subsidiaries could provide under uncertainty because they typically modify products and even manufacturing processes to meet local needs (Bartlett & Ghoshal, 1989). Therefore, to exercise the option to switch within a multinational network could be very costly due to local autonomy and localization of products and production. Whether and to what extent multinationality provides operating flexibility depends on a variety of contingencies and is an empirical question.

The several empirical studies in Focus 3 address different aspects of real options theory on multinationality. Rangan (1998) examined whether firms substitute inputs from other countries in the production process when the exchange rate changes, which is a direct test of the exercise of real options embedded in multinationality. Using data on the U.S. MNEs' operations abroad and foreign MNE operations in the U.S. from 1977 to 1993, Rangan (1998) found that MNEs systematically exploit currency shifts but to a relatively modest degree.

The remaining work did not test the exercise of real options directly but focused on the examination of the relationship between multinationality and a variety of performance indicators such as market valuation, corporate risk, corporate exposure, and capacity expansion, which are indirect tests of the predictions of real options theory. Three studies, Allen and Pantzalis (1996), Tang and Tikoo (1999), and Pantzalis (2001) tested market valuation of multinationality. Allen and Pantzalis (1996) measured the value derived from operating flexibility as the difference in the market value between MNEs and comparable domestic firms. They used two variables to capture the network structure of MNEs: breadth (number of foreign countries in which MNEs have operations) and depth (the concentration of foreign subsidiaries in a few countries). They used the information about foreign and US affiliations of firms operating in the United States for the year 1991 to find that returns to multinationality are maximized for firms with networks that have breadth but not depth. Therefore, returns to multinationality increase as firms expand their holdings of real options by widening the breadth of their transnational network but decrease with the acquisition of redundant real options by increasing the subsidiaries in each country because of increased agency costs. Consistent with this idea, Tang and Tikoo (1999) used information on 1,280 U.S. manufacturing firms and found that securities markets respond more to earnings changes of MNEs that have breadth than to those that have depth.

Based on financial data of U.S.-based mining and manufacturing MNEs in 1990, Pantzalis (2001) found that the average market value of MNEs whose network of subsidiaries does not include operations in developing regions is substantially lower than that of MNEs with operations in developing areas. This finding suggests that the value of the real options portfolio that MNEs possess increases when they operate across segmented markets.

Using U.S. manufacturing firms as a sample, Reuer and Leiblein (2000) tested the impact of multinationality and IJVs on the reduction of corporate risks. To measure corporate risks, Reuer and Leiblein (2000) used the probability of failing to meet a performance objective or to meet an expected loss. They found that U.S. manufacturing firms' investments in dispersed foreign direct investment (FDI) and IJVs do not have a negative impact on organizational downside risk, which is inconsistent with predictions from real options theory. Furthermore, Tong and Reuer (2007) have also investigated the downside risk implications of multinationality and found that a curvilinear relationship exists between multinationality and downside risks of MNEs, which suggests that MNEs benefit from the switching options among dispersed subsidiaries while suffering from various coordination costs needed to realize the switching options.

Miller and Reuer (1998a) compared the effect of export with that of FDI on MNEs' economic exposure to exchange rate movements. Economic exposure refers to the sensitivity of a company's real value to environmental contingencies, such as changes in foreign exchange rates. Using data from U.S. manufacturing firms, the authors found that FDI reduces MNEs' economic exposure to foreign exchange rate risks, whereas export has no such impact. Miller and Reuer (1998b) also compared the economic exposure that U.S. manufacturing firms face during the periods of currency appreciation and depreciation and found that the economic exposure is *asymmetric* between the two periods, which indicates that firms do possess real options for managing foreign exchange exposures. Campa (1994) compared the capacity expansion decisions of MNEs with those of domestic firms. Based on a sample of chemical processing industries from 1977 to 1988, Campa (1994) found that exchange rate uncertainty has negative effects on capacity expansions of domestic firms, whereas the uncertainty has no effect on the probability of entry investments by MNEs. Thus, MNEs are better able to manage exchange rate uncertainty by shifting their production to different countries.

These empirical findings – only under certain conditions can multinationality increase market valuation and reduce corporate risks and corporate exposure – call for more careful examination of the contingencies under which a multinational network brings extra value for MNEs. Generation of real options (building a multinational network) does not necessarily imply value creation or risk reduction. Only when the multinational network could realize the option value of switching raw materials, production, and sales across subsidiaries when opportunities arrive, will multinationality have a positive impact on the market valuation of an MNE and a negative effect on corporate risk. Hence, MNEs are more likely to achieve global efficiency or low corporate risks when they have higher capabilities in recognizing, creating, and exercising real options within a multinational network. Future studies are needed to examine what factors will influence these capabilities.

Choice of Market Entry Mode

Among different market entry modes, such as WOSs, IJVs, export, and licensing, IJVs are the most widely analyzed based on a real options approach. These studies (Foci 4, 5, and 6) mainly answer two questions: (1) Can IJVs be viewed as real options? and (2) Under what conditions can IJVs provide a higher option value? An IJV can be viewed as real options because it provides a partner with the ability to exploit the upside potentials by acquiring the other partner's equity if uncertainty from market environment and internal partnerships turns out to be favorable (i.e., the option to grow) as well as the ability to avoid downside losses by selling its equity to its partner or dissolving the IJV when uncertainty turns out to be unfavorable (i.e., the option to abandon) (Buckley & Casson, 1998; Chi & McGuire, 1996; Chi & Seth, 2002; Cuypers & Martin, 2007). Further, an IJV provides a higher real option value when joint venture partners have divergent valuation of the IJV (Chi & McGuire, 1996). However, empirical studies that test the option value brought about by IJVs are rare.

Focus 4: Market Entry Modes/Real Options Reasoning
Real options theory suggests that choice of market entry mode should no longer be viewed as static decision making. Indeed, a market entry mode should be evaluated not only by the NPV of its future profits but also by the option value it could bring to the MNE, that is, the value from adjusting future entry modes in response to new information. Specifically, an entry mode can provide two types of options: the option to grow (spot and exploit market opportunities) and the option to abandon (spot market disadvantages and withdraw from the market). A natural question arises: Which entry mode provides the highest option value?

As shown by Buckley and Casson (1998), an IJV is likely to provide a higher option value than a WOS, licensing, or export. Buckley and Casson (1998) first compared the merits and weaknesses of a WOS with export/licensing. A WOS captures more information about the host environment than export/licensing since ownership of assets confers ownership of information, which implies that if volatility caused the market to grow unexpectedly, the foreign investor with a WOS would recognize the opportunities and respond quickly. In addition, the MNE with a WOS faces lower costs of capacity expansion than does an exporter or licensor who decides to switch to foreign production. Thus, the value of the option to grow in a WOS is higher than that in export/licensing. However, in response to market decline, the MNE faces more constraints than an exporter or a licensor, because the MNE has devoted more irreversible investment to a WOS than to export/licensing. Hence, a WOS provides a lower value of the option to abandon than export/licensing.

Buckley and Casson (1998) further emphasized that an IJV provides a better combination of characteristics than other entry modes when both the option to grow and the option to abandon are important. An IJV provides a higher growth option value than export/licensing because the MNE can respond to favorable market signals quickly by buying the partner out when there is unexpected market growth. Meanwhile, an IJV provides a higher abandonment option value than a WOS because the partner provides a ready market for divested assets. Nonetheless, there may be disadvantages in the formation of an IJV because partners themselves can become a new source of volatility, which will reduce the option value of an IJV.

However, Buckley and Casson (1998) ignore the option to learn in IJVs. Through collaborations with local firms, MNEs have the option to gain knowledge about how to do business in the host country that will influence their decisions in subsequent business activities in this country or countries with similar cultural, social, economic, and political environments. Such a learning option increases the option value of an IJV.

Focus 5: Market Entry Modes/Real Options Modeling

Chi and McGuire (1996) investigated the conditions under which options provided by IJVs are valuable. The model combines the key elements in real options theory with those in transaction cost theory in explaining the value of the option to expand or divest. The sources of uncertainty are the two joint venture partners' valuation of the same joint assets. Chi and McGuire (1996) used a simple binomial model from Cox et al. (1979) to conclude that the real options value of a joint venture depends on how partners forecast the expected value of the IJV; the option value is higher when partners have divergent expectations of the value of the joint assets. Intuitively, the partner with higher valuation is willing to pay a higher price than the other partner does, which will result in a mutually beneficial trade in their stakes. On the contrary, if partners have similar valuation of the IJV, the option to acquire cannot be realized, and partners cannot benefit from any trade in their stakes.

Focus 6: Market Entry Modes/Empirical Testing
As mentioned previously, empirical testing of market entry modes based on a real options approach is rare. Real options reasoning and modeling suggest that there could be three types of empirical tests on market entry modes. First, we can empirically test how exogenous and endogenous uncertainty influences choice of market entry mode and governance structure (e.g., whether the existence of exogenous and endogenous uncertainty encourages the establishment of IJVs). Second, we can analyze whether resolution of uncertainty triggers changes in market entry modes (e.g. whether resolution of uncertainty triggers ownership changes in IJVs). Third, we can indirectly test whether and how much the stock market recognizes the option value of IJVs, including the option to grow, the option to abandon, and the option to learn.

The study by Reuer and Tong (2005) falls into the first category, where they investigated what factors motive IJV partners to have explicit clauses on call options to acquire equity. Reuer and Tong (2005) compared the predictions from transaction cost theory and real options theory. The transaction cost perspective proposes that a company is more likely to use explicit option clauses in joint ventures in *core* businesses because the company risks losing proprietary knowledge during the course of the collaboration. However, real options theory predicts that it is more attractive to have explicit call options in *non-core* businesses because a company faces more sources of uncertainty due to unfamiliarity with the businesses, and it is more valuable to have explicit call options to keep managerial flexibility of scaling up investments if the businesses develop favorably. Their results showed more support to the transaction cost perspective, that is, MNEs are likely to use explicit call options in IJVs with core businesses.

The study by Kouvelis, Axarloglou, and Sinha (2001) falls into the second category, where they examined the impact of exchange rate volatility on MNEs' choice of appropriate ownership structure for production facilities. They used the information from 187 U.S. MNEs and found that a strongly depreciated home currency encourages the use of export, whereas a strongly appreciated home currency encourages the use of IJVs or WOSs. However, the high costs of switching between different strategies forced a period of inaction during which the MNE continues to use its current mode, even if the immediate profits favor switching strategies. Such inaction is reinforced when the volatility of exchange rates is high.

The study by Tong et al. (2007) belongs to the third category of empirical test, where they examined specifically whether and when firms capture the growth option values embedded in IJVs. Tong et al. (2007) provided the following theoretical arguments: (1) the number of IJVs enhances the growth option value, (2) minority IJVs provide a higher growth option value than majority IJVs, (3) noncore IJVs provide a higher option value than IJVs in core businesses, and (4) IJVs in emerging economies provide a higher option value than those in developed economies. Empirically, Tong et al. (2007) calculated the growth option value of firms and found that minority and non-core IJVs contribute to a higher value of growth options.

The limited number of empirical studies in this category indicates that more empirical studies are needed to examine the option value of IJVs. For example, Kouvelis et al. (2001) examined the impact of exogenous uncertainty on choice of entry modes. However, it is not clear about how endogenous uncertainty influences a firm's choice of entry modes. Moreover, as presented later, more empirical studies can be carried out regarding the sequential decision making in entry modes.

Choice of Market Entry Timing

Market entry timing here refers to the timing to initiate or increase an investment in a foreign market. The papers in this section (Foci 7, 8, and 9) support the following ideas: on the one hand, it has been recognized that the option to defer an investment is valuable under conditions of uncertainty and irreversibility of investment; on the other hand, factors that may negatively influence the option value to defer investment include market competition, the option to grow, and the option to learn (Folta & O'Brien, 2004; Kester, 1984; Kulatilaka & Perotti, 1998). Existing empirical studies focus on testing the relationship between uncertainty and investment timing of foreign investments at an aggregate industry level, while very limited studies have examined the impact of uncertainty on market entry timing of foreign investments at the individual firm level.

Focus 7: Market Entry Timing/Real Options Reasoning

Rivoli and Salorio (1996) applied real options theory to address the timing issue of FDI and compared the benefits and costs of immediate investments and late investments. Investment deferment provides an MNE with an opportunity to wait for more relevant information to make wise decisions regarding whether to enter the market and how much to invest. This delay option is particularly appropriate if the MNE is likely to maintain its ownership advantages over a long period, and if the investment is difficult to reverse. However, when the market becomes competitive, and/or the option exercising right is not proprietary (i.e., many MNEs have similar options to enter the market), the MNE is more willing to exercise the option rather than delay it because, in doing so, it can enjoy first mover advantages and obtain an option to grow.

However, Rivoli, and Salorio (1996) paid attention only to the option to defer or grow but ignored the option to learn as another advantage from immediate investments. Learning through immediate investments can contribute to information collections and uncertainty reduction. For example, the timely capital infusion in new technologies helps to develop and learn about a technology and its prospects for success (Folta & Miller, 2002; McGrath, 1997).

Focus 8: Market Entry Timing/Real Options Modeling

Dixit (1989) provided a classic example of modeling the optimal timing of an investment. The model involves a foreign firm that produces a good abroad and has an option to sell its good in the U.S. market at a constant market price. This option has an exercise price, which is the sunk cost of entering the market. Although the firm faces a certain price in US dollars, its returns in home currency fluctuate due to an uncertain bilateral exchange rate. Formally, the exchange rate follows a stochastic process. Dixit (1989) solved the formal model and concluded that even a risk neutral firm will decide not to enter the market and hold the option for one more period as long as the expected change in the value of the option is higher than the expected return from entering the market for one period.

Focus 9: Market Entry Timing/Empirical Testing

There could be two types of empirical tests of market entry timing. The first type tests entry timing of foreign investments at the aggregate industry or country level, whereas the second type examines entry timing at the firm level. The study of Campa (1993) belongs to the first type, but no studies belong to the second type. Based on the insight in Dixit (1989), Campa (1993) tested if firms that exported to the U.S. market deferred their investments to enter the market during the 1980s due to the fluctuations of the U.S.'s real exchange rate. Campa (1993) used a sample of foreign investments in 60 U.S. wholesale industries and found that exchange rate volatility is negatively correlated with the number of foreign investments that occur in these industries. This negative effect is most pronounced for industries where sunken investments in physical and intangible assets are relatively high, that is, the irreversibility of investment is high.

Summary

Fig. 1 summarizes the logic of real options theory and its applications to international strategy as identified in the previous nine foci. To generate better performance, MNEs first have to recognize different types of uncertainty in the market: exogenous and endogenous uncertainty. MNEs then create real options – such as the option to switch, the option to grow, and the option to learn – by building multinational networks and choosing market entry modes and timing. The value of real options is realized when MNEs exercise the options in response to new information. Therefore, real options generate value for MNEs (increasing market valuation and decreasing corporate risks) when the whole process of option generation and execution is properly implemented (Copeland & Tufano, 2004).

The literature review in this section shows that empirical studies on the intersections of real options theory and international strategy are still at an emerging stage. Fig. 1 suggests that there could be three types of empirical studies. First, we can examine how exogenous and endogenous uncertainty influences an MNE's strategic decision making, such as choice of multinational networks, and choice of market entry modes and entry timing. Second, we can examine the conditions under which MNEs exercise real options embedded in multinational networks, entry modes, and entry timing. Third, we can examine how generation and exercise of real options impact an MNE's performance, such as market valuation and

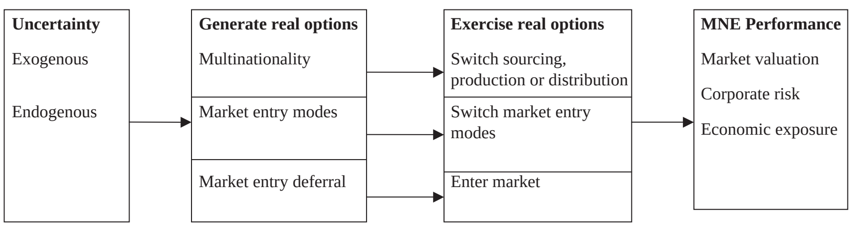

Fig. 1. Real Options Theory and International Strategy.

corporate risks (see Reuer and Tong (2007) for more information on empirical testing).

THE ROAD AHEAD

The previous section shows that more empirical work is needed to test how uncertainty influences the way MNEs conduct international business. However, the potential of real options theory to international strategy is not limited to such specific topics as multinational network, entry mode, and entry timing. In this section, I further analyze the potential contributions that real options theory could add to existing theories in international strategy. Specifically, I first discuss the differences between transaction cost theory and real options theory in handling uncertainty and present the implications for research in international strategy. I then show how real options theory could contribute to a more dynamic theory in international strategy by enriching internationalization theory. Five testable propositions are derived.

Uncertainty and Governance Choice: Comparisons between Transaction Cost Theory and Real Options Theory

The insights we get from real options theory imply that some basic concepts in transaction cost theory have to be reconsidered in determining governance structure under uncertainty. As shown in Table 5, we argue that the two theories differ in several aspects in handling uncertainty. First, the two theories have different decision-making rules in determining governance structure. Transaction cost theory attaches more importance to keeping control ex ante to minimize transaction costs arising from behavioral uncertainty (Williamson, 1985), whereas real options theory emphasizes keeping flexibility in facing exogenous and endogenous uncertainty and taking actions ex post to take advantage of new information (Dixit & Pindyck, 1994; Trigeorgis, 1996).

Second, the two theories present different assumptions on uncertainty. Transaction cost theory strongly emphasizes using governance structure to curb the negative impact of one type of uncertainty: behavioral uncertainty (Williamson, 1985). Potential partner opportunism may arise due to asset specificity, which refers to the investments an exchange partner makes that are highly specialized to a few trade partners and can be redeployed

Table 5. Comparisons between Real Options Theory and Transaction Cost Theory.

	Real Options Theory	Transaction Cost Theory
Decision-making rules	Keep flexibility in facing exogenous and endogenous uncertainty and take actions ex post to take advantage of new information.	Keep control ex ante to minimize transaction costs arising from behavioral uncertainty.
Basic assumptions about uncertainty	Consider various types of exogenous and endogenous uncertainty. Uncertainty implies risks as well as growth opportunities.	Mainly consider one type of uncertainty: potential partner opportunism. Uncertainty is not important when there is low asset specificity. Uncertainty is related to high transaction costs when there is high asset specificity.
Methods to handle uncertainty	Active way to handle uncertainty. MNEs should keep flexibility to benefit from uncertainty, even when asset specificity is high.	Passive way to handle uncertainty. MNEs should keep high control on investments if uncertainty and asset specificity are high.
Time frame	Present a systematic method to capture the interactions between uncertainty and firm behavior in a dynamic environment.	Present a systematic method to analyze choice of governance in a static environment.

only by sacrificing productive value. On the contrary, real options theory considers the impact of a larger variety of exogenous and endogenous uncertainty where behavioral uncertainty is only one type of endogenous uncertainty.

In transaction cost theory, asset specificity instead of uncertainty is the main variable; uncertainty raises attention only when asset specificity is high. Specifically, when asset specificity is low, uncertainty will not cause substantial transaction costs, and therefore MNEs should maintain flexibility by adopting low-control governance structure (Anderson & Gatignon, 1986; Williamson, 1985). However, when asset specificity becomes high, uncertainty could cause significant transaction costs, which makes high ownership control necessary. For example, Anderson and Gatignon (1986) argued that facing the combination of asset specificity and country risks, an

MNE should employ high-control market entry modes in order to curb potential partner opportunism related to country risks. On the contrary, in real options theory, uncertainty is the most important parameter; uncertainty is associated with potential opportunities and challenges, more than potential partner opportunism and transaction costs. Real options theory is about how to benefit from uncertainty; strong control and commitment may make MNEs less flexible in taking advantage of new information.

Third, closely related to the previous point, transaction cost theory and real options theory suggest different emphases on control and flexibility when facing uncertainty. Real options theory presents ways to keep flexibility so as to strategically benefit from uncertainty, whereas transaction cost theory shows passive methods to control costs related to uncertainty. Real option theory suggests that when uncertainty that MNEs face is high, the option to defer control and commitment becomes important; MNEs should use low-control ownership structures to keep managerial flexibility and should not commit to highly irreversible investments in the first place (Rivoli & Salorio, 1996). The low-control and commitment entry modes not only limit MNEs' investment losses when the future unfolds unfavorably but also serve as platforms for business expansions for future opportunities.

Given the situation where asset specificity is high and uncertainty is sufficiently high, it is likely that under certain conditions, the value from strategic flexibility is more than benefits from control, which leads to the preference of low-control governance structure. Although Folta's (1998) empirical study is not framed in an international context, it is a good example to illustrate this point. Specifically, Folta (1998) tested how uncertainty influences a firm's choice between joint ventures and outright acquisition in order to obtain a desirable technology. Transaction cost theory predicts that acquisitions are preferred over joint ventures because R&D activities are often highly proprietary and greater degrees of ownership will provide a degree of administrative control for dealing with potentially opportunistic partners. However, real options theory suggests that technological uncertainty encourages the use of joint ventures because limited investments in joint ventures minimize a firm's exposure to technological risks as well as provide an option to acquire the target firm in the future when uncertainty is resolved favorably. Using a sample of 402 transactions in the biotechnology industry, Folta (1998) found evidence to support the predictions of real options theory.

The last difference between the two theories in developing international strategy is that transaction cost theory presents a systematic method to analyze choice of governance in a static environment, while real options theory presents a systematic method to capture the interactions between uncertainty and firm behavior over time and thereby provides insights on the dynamic choice of governance over time. Theories based on transaction cost analysis focus on equilibrium choice and do not leave much room for analyzing transitional modes in a dynamic setting (Seth & Chi, 2005). Real options theory emphasizes that FDI decisions are not now-or-never decisions; MNEs have the option to speed up or slow down their investments with more available information. Their choice of governance on market entries may follow a pattern, contingent on reduction of uncertainty. (More details will be discussed in the next subsection regarding how real options theory enriches internationalization theory.)

In summary, transaction cost theory advocates that governance structure should be used to minimize transaction costs which arise from asset specificity and behavioral uncertainty, whereas real options theory emphasizes that governance structure should be employed to provide flexibility when facing uncertainty in order to benefit from potential opportunities and avoid potential losses in the future. Formally, we reach the following proposition based on real options theory.

Proposition 1. When exogenous and endogenous uncertainty increases, choosing a governance structure which affords high control over international investments with asset specificity becomes less beneficial.

Proposition 1 indicates that when choosing an appropriate governance structure, an MNE should balance the benefits from control and flexibility. In other words, governance structure does not necessarily reflect either transaction cost concerns or strategic flexibility concerns; instead, governance structure should reflect both of them. It is not surprising that Gatignon and Anderson (1988) did not find empirical evidence to support their proposition that the combination of country risk and asset specificity leads to high-control entry modes, because, from a real options perspective, high country risk reduces the benefits from high control.

Several studies have explored this idea that an MNE should choose governance structure to minimize potential transaction costs as well as keep flexibility in response to new information. For example, Chi and McGuire (1996) proposed that an MNE should use an option-to-acquire clause in IJVs when collaborating with new partners, or when the host country does not provide adequate protection of intellectual property. By having such a clause, a firm keeps control of its strategic assets (it can always acquire the other partner to avoid partner opportunism) as well as maintains the flexibility to react to future market information. In a similar vein, Reuer and Tong (2005) found that firms often use explicit call option clauses as contractual safeguards to minimize potential opportunistic behaviors of partners in IJVs that fall into their core businesses and in IJVs operating in host countries with loose protection of intellectual property rights.

Hence, although transaction cost theory and real options theory have examined uncertainty from different perspectives, they also complement each other in determining the governance structure. Future studies should focus on the integration of the two theories in examining firms' governance decisions in a foreign country.

Real Options Theory and Internationalization Theory

The stages model of internationalization theory proposes that firms gradually increase commitments to foreign markets; firms often begin by exporting to a foreign market, then set up a selling or distribution subsidiary, and finally form a production subsidiary, such as an IJV or a WOS (Johanson & Vahlne, 1977; Sullivan & Bauerschmidt, 1990). However, one can easily find exceptions to the staged path of expansion supported by internationalization theory, thereby reducing its empirical validity or generality (Benito & Gripsrud, 1992; Fina & Rugman, 1996). Real options theory can provide a rigorous economic rationale for the incremental internationalization process as well as prescribe boundary conditions under which it is optimal to invest incrementally.

Specifically, real options theory suggests that an incremental internationalization process provides MNEs with a series of options, including the option to defer, the option to grow, and the option to learn. On the one hand, low-commitment market entries at early stages provide the option to defer high-commitment market entries and work as platforms for MNEs to exercise growth options in later stages of internationalization. Early low-commitment market entries also provide learning options to accumulate experience and reduce endogenous uncertainty in culture, market demand, partner behaviors, and local business environment, etc. Such learning options are valuable because they facilitate a more reliable prediction of the efficacy of an MNE's non-location bounded firm-specific advantages in the local market (Buckley et al., 2002) as well as help recognize market opportunities and the optimal timing to exercise growth options in growing markets and economic upturns. On the other hand, incremental internationalization avoids lump sum irreversible investment losses and helps an MNE persist longer in difficult markets and economic downturns.

Real options theory not only provides an economic explanation for the incremental internationalization process but can also help analyze the speed of the internationalization process. In other words, what are the factors that trigger an MNE from using low-commitment to high-commitment entries? Real options theory suggests that the main one is the reduction of uncertainty, including both exogenous and endogenous uncertainty. When exogenous uncertainty is highly unresolved, MNEs will not increase market commitment because the option to defer is valuable. When exogenous uncertainty reveals unfavorably, MNEs will not increase market commitment either or may even exercise the option to decrease resource commitment to the local market. Only when exogenous uncertainty resolves favorably will MNEs have the opportunity to exercise the option to increase resource commitment to the local market. However, whether an MNE is ready to exercise the option to grow and to explore potential opportunities depends on the extent to which it has reduced endogenous uncertainty through accumulation of local knowledge. Thus, the increase in resource commitment depends on the reduction of both exogenous and endogenous uncertainty.

Here, we need to link real options theory with the organizational learning literature to examine how MNEs achieve reductions of endogenous uncertainty. Uncertainty reduction is accomplished through knowledge accumulation and organizational learning at multiple levels. As found in the previous literature on sequential market entries, MNEs can learn not only from their own experiences in a particular country (Chang, 1995) but also from their experiences in 'near market' (Mitra & Golder, 2002) and previous behaviors of competitors and business groups (Guillén, 2003). As MNEs gain experience in the host country, learn about local practices, build relations with local suppliers, and recruit local employees, the liability of foreignness will diminish (Chang & Rosenzweig, 2001). As such, favorable signals from the market or political environment are likely to encourage MNEs to increase commitment to the local market. Kogut and Chang (1996) provide a good example to support this assertion. They found that initial investments of Japanese firms in the United States help to accumulate experience, reduce endogenous uncertainty, and serve as platforms for sequential investments; when exogenous uncertainty in real exchange rates resolves favorably, Japanese firms act to expand their investments.

The previous arguments indicate that when facing high uncertainty, the option to defer is valuable, and thus an MNE hesitates to switch from low-commitment to high-commitment market entries. We further consider the moderating effect of an important factor – the option to grow – that may encourage MNEs to speed up the internationalization process even when facing high uncertainty. First, when high-commitment market entry modes or investment scales contribute significantly to the reduction of uncertainty and thereby produce valuable growth options, MNEs may jump to high-commitment entry modes or scales rather quickly. For example, Delios and Henisz (2003) found that Japanese MNEs are more likely to employ joint ventures over distributional entries in a host country with high policy uncertainty because they may leverage the influence of their joint venture partners to reduce policy uncertainty in the host country.

Second, MNEs may skip or shorten the time period of export/licensing and adopt high-commitment entry modes rapidly in order to gain first mover advantages, preempt competition, and obtain valuable growth options ahead of their competitors. Based on a game theoretical model, Kulatilaka and Perotti (1998) reinforce this idea: By investing aggressively under high uncertainty, a firm may be able to preempt potential entries or force existing competitors to "make room" for its entry. If this strategic effect is significant, the growth options embedded in the investment likely become more valuable than the deferral option, even though high uncertainty may imply larger risks. For example, Volkswagen, a prestigious German automaker, entered China in the early 1980s by building a joint venture with a local Chinese automaker, despite high uncertainty in political environment and in economic policy toward FDI. Being the first mover into the market, Volkswagen has obtained valuable growth options and enjoyed a market share of more than 50% in the sedan market in China for more than a decade. Buckley and Tse (1996) provided another example: many U.S. and European companies made an initial move by way of FDI to Eastern Germany immediately following the coming down of the Berlin wall. Since these companies have already gained experience in doing business in Western Germany, they intend to enter aggressively to Eastern Germany to preempt competitors and gain growth options.

To sum up, the speed of the internationalization process depends on the tension between the option to defer and the option to grow. Switching market entry modes or scales from low-commitment to high-commitment ones loses the option to defer but gains the option to grow. Therefore, the speed of internationalization relies on which option is more valuable. When uncertainty, both exogenous and endogenous, is highly unresolved, the option to defer becomes relatively more valuable, whereas the option to grow becomes more important when both types of uncertainty resolve favorably, or when firms are able to proactively reduce uncertainty or competitive threats from other companies. Therefore, we reach the following propositions based on real options theory.

Proposition 2. MNEs are more likely to speed up the incremental internationalization process when exogenous and endogenous uncertainty is resolved favorably.

Proposition 3. When uncertainty is high, MNEs are more likely to speed up the incremental internationalization process when benefits from preempting competitors are high, or when high resource commitment contributes to the reduction of uncertainty.

A direct application of the previous propositions is about mode-transition decisions in IJVs. One way to speed up the internationalization process is through IJV transitions, that is, MNEs can increase commitments to the market by acquiring equity from their partners in IJVs. Previous research on transitional decisions in IJVs has seldom considered these decisions as exercise of real options in IJVs. Rather, previous research, mainly based on transaction cost theory, has examined the impact of transaction cost related factors such as inter-partner conflict and cultural distance on acquisition decisions in IJVs (e.g., Hennart, Roehl, & Zietlow, 1999; Kogut, 1989; Park & Russo, 1996; Reuer, 2000). Real options theory suggests that IJV transitions likely follow the same patterns as those in Propositions 2 and 3, that is, MNEs' decisions of acquiring their partners' equity are related to the resolution of exogenous and endogenous uncertainty, as well as to the impact of such acquisition on uncertainty resolution and competition.

In addition, some studies, such as Kogut (1991) and Folta and Miller (2002), although not framed in an international context, provide some insights on IJV transitions in relation to uncertainty. Specifically, Kogut (1991), based on a sample of 92 manufacturing joint ventures, found that unexpected growth in the product market increases the likelihood of acquisition of joint ventures by partners. Furthermore, Folta and Miller (2002) used an event history model to examine when a partner acquires additional equity in research-intensive joint ventures. The data from minority investments in the biotechnology industry in the U.S. support the ideas that (1) low uncertainty in high-valued technologies motivates the exercise of the option to acquire additional equity in joint ventures, and (2) when the growth option is at risk of preemption by rivals, greater uncertainty encourages the exercise of the option to acquire. To sum up, we reach the following propositions based on real options theory.

Proposition 4. MNEs are more likely to acquire equity from local partners in IJVs when exogenous and endogenous uncertainty is resolved favorably.

Proposition 5. When uncertainty is high, MNEs are more likely to acquire equity from local partners in IJVs when benefits from preempting competitors are high, or when high resource commitment contributes to the reduction of uncertainty.

CONCLUSION

An exciting new area of research within the field of international strategy is the application of real options theory to decision making of MNEs under uncertainty. Uncertainty is a feature of doing business internationally. Traditional theories in international strategy based on transaction cost analysis associate uncertainty with transaction costs and potential losses and thereby suggest strategies to minimize transaction costs, e.g., using high equity ownership to reduce transaction costs. These theories, however, do not suggest strategies to actively benefit from uncertainty. Real options theory thereby contributes to the field by introducing a new way of thinking, i.e., uncertainty implies risks as well as opportunities, and firms are able to benefit from uncertainty by creating real options (such as the option to defer, the option to grow, and the option to learn) to maintain flexibility in response to new information.

Existing applications of real options theory to international strategy have focused on how firms can generate real options and benefit from uncertainty through the establishment of multinational networks and choice of market entry mode and market entry timing. Beyond the existing applications, real options theory has the potential to substantially enrich existing theories in international strategy. It can contribute to the design of governance structure by emphasizing the value of options and flexibility, a research area that is well dominated by transaction cost economics. Real options theory can also enrich studies on sequential decision making in international strategy such as the internationalization speed and mode-transition decisions in IJVs. I have incorporated these ideas in five propositions in the paper. I hope that this paper will stimulate more theoretical and empirical applications of real options theory to the field of international strategy.

NOTES

1. Miller and Arikan (2004) classify real options theory into two types: real options reasoning and real options pricing. Here, we use the term "real options modeling," because option-pricing techniques are often combined with economic models to make meaningful contributions to the theoretical development in international strategy.

2. It needs to be acknowledged that theories in international economics have largely recognized that irreversibility and uncertainty are important in MNEs' decision-making. This study has found a "hysteresis effect" (an effect that persists after the cause that brought it about has been removed) when firms respond to exchange rate changes (Krugman & Baldwin, 1987). For example, as the U.S. dollar has fallen from its 1985 heights, the U.S. trade balance has been slow to improve, and foreign firms have been reluctant to raise their prices in the U.S. market. Dixit (1989, 1992) suggested that firms that refuse to invest under favorable situations may be optimally waiting to make sure that this state of affairs is not transitory, while those who could carry large losses may be rationally keeping their operations alive on the chance that the future may be brighter.

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JOINT VENTURES AND REAL OPTIONS: AN INTEGRATED PERSPECTIVE

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ABSTRACT

We provide a comprehensive synthesis and extension of the real option (RO) literature on joint ventures (JVs), contributing in three main areas. First, we examine major alternative theoretical perspectives on JVs – learning, bargaining, transaction cost and agency theory – to elaborate how they complement or contradict RO predictions. Second, we compare arguments and variables used to explain different JV stages – initial RO explicitness and equity shares, JV stability, and performance consequences – and highlight research opportunities. Third, we discuss and extend research about behavioral aspects of making RO (JV) investments. Overall, we offer new predictions and suggestions for a better integration within the RO literature, and between RO and related literatures on JVs.

INTRODUCTION

In recent years, real option (RO) theory has emerged as an important approach to understand and value strategy under uncertainty. Accordingly,

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numerous types of investments such as R&D projects, taking out patents, investing in human capital, subcontracting, and entering into joint ventures (JVs), which are all characterized by uncertain outcomes, have been studied from an RO perspective (e.g. Bowman & Moskowitz, 2001; Chi & Levitas, 2007; Nerkar, Paruchuri, & Khaire, 2007; Fister & Seth, 2007; Van Mieghem, 1999; Reuer & Leiblein, 2000).

In this paper, we focus on one type of investment, namely JVs, which we define as equity-based collaborative arrangements whereby two or more organizations each contribute resources, including equity, for the joint pursuit of economic goals (Martin & Salomon, 2003b). It has long been established that firms often use JVs to enter into unfamiliar and risky product markets and geographic areas (Aharoni, 1966; Harrigan, 1988). Accordingly, though JVs may vary in their form and functional purpose(s), they are generally surrounded by high levels of uncertainty (Martin, Mitchell, & Swaminathan, 1995; Krishnan, Martin, & Noorderhaven, 2006).[1] This is especially – but not exclusively – the case for international joint ventures (IJVs), which are subject to powerful sources of uncertainty such as cultural differences and the burdens of operating across multiple locations and jurisdictions (e.g., Martin & Salomon, 2002, 2003a; Reuer & Tong, 2005).[2] Furthermore, JVs allow for, and are subject to, ongoing adjustments in the terms of the agreement (and the relationship among parent firms). These features make JVs – and IJVs in particular – both suitable and important to study from an RO perspective. Indeed, the application of RO theory to JVs has led to numerous insights and an improved understanding of collaborative ventures. Still, there remain a number of promising opportunities for future research on JVs from an RO perspective, and several theoretical and empirical gaps and inconsistencies exist. Therefore, our objective in this paper is to provide a comprehensive synthesis and extension of the RO literature on JVs. Where relevant, we offer new testable propositions. We aim to make contributions in three areas.

First, several theoretical perspectives besides RO theory can be used to study JVs. In fact, cooperative ventures lend themselves to a particularly broad range of explanatory perspectives, which sometimes lead to sharply differing conclusions (Martin, Mitchell, & Swaminathan, 1994; Cuypers & Martin, 2006a). Therefore, we revisit the most important related literatures on JVs – including learning, transaction cost, bargaining models and agency theory – and link them to the RO literature, with a view to elaborate on the relationships between these theories.

Second, one of the most attractive features of RO theory is that it is a dynamic perspective that can explain each of a JV's stages, from formation to subsequent adjustment and post-JV outcomes (sale, dissolution, etc.). To make the best of such a dynamic theory requires consistency in researching sequential stages. Although various JV stages have been duly studied from an RO perspective, there are differences in the scope and content of studies of the various JV stages. Therefore, we compare the theoretical arguments and explanatory variables used to explain different JV stages, to highlight important research opportunities and offer predictions and suggestions toward a better integration within the RO literature.

Finally, we address the behavioral aspects of making RO investments. Recent developments, including some applications to the RO literature, have not been fully incorporated into JV research. We examine these ideas and discuss their implications for JV research.

EXPLICIT AND IMPLICIT REAL OPTIONS IN JOINT VENTURES

Shortly after the formalization of financial option theory, scholars recognized that financial options logic could be applied to corporate investments (Myers, 1977). These options on nonfinancial assets have been labeled ''real options'' and can be seen as contingent investment commitments that secure future decision rights (Trigeorgis, 1993).

The insights and techniques from financial option theory have shown that the traditional net present value (NPV) valuation approach does not fully capture the value of an investment. The traditional NPV approach should be expanded to take into account management's flexibility to adapt to unexpected developments (Trigeorgis, 1995). Such flexibility is valuable because it can limit investors' downside losses to their initial investment, while preserving the upside potential. Thus, the expanded NPV approach should incorporate both a passive NPV component and a dynamic option value component (Pindyck, 1988):

$$\text{Value of an investment} = \text{``passive NPV'' of expected cash flows} + \text{``dynamic real option'' value}$$

However, these two different value components usually have to be captured in different ways, requiring differently structured investments – in terms of share of the total investment, absolute size of the investment, scope and sequencing of the project, etc. (e.g., Reuer & Tong, 2007). For instance, with regard to JV investments, capturing the passive NPV component requires taking a larger percentage stake in the JV, holding its size constant, in order to capture as much of the cash flow as possible; while capturing the dynamic option component requires taking a smaller stake (Chi & McGuire, 1996), which secures future decision rights while minimizing the initial sunk costs (and therefore downside risk). Meanwhile, an option-like investment by a firm to seek new technology (without partner) corresponds with a smaller (absolute) investment while an investment to capture the NPV component corresponds with a larger (absolute) investment (Hurry, Miller, & Bowman, 1992).

Among the first to apply RO theory to JVs, Kogut (1991) argued that firms can use a JV to capture the upside potential of an investment by buying out the partner in a later stage when favorable information becomes available, while limiting their exposure to the initial investment. This option to acquire can be explicit, but this is not a necessity.[3] It remains possible, when there is no ex ante contractual specification of the strike price, or of the party holding the acquisition right, for the parties involved to negotiate the acquisition and sale of their share at a later stage. Therefore, a JV has at least an embedded implicit call option[4], i.e., an option to acquire a partner's stake (Chi & McGuire, 1996; Chi, 2000). Furthermore, Chi and McGuire (1996) and Chi (2000) argued that the presence of an explicit option clause will depend on three conditions: (1) the level of uncertainty,[5] (2) the anticipation of a change in the relative bargaining power of the two parties during their collaboration, and (3) ex ante asymmetry between both parties in their expected payoffs of the option. Only the first determinant has received empirical attention. Reuer and Tong (2005) studied empirically the determinants of having an explicit option to acquire additional equity in a JV making use of transaction costs theory and RO theory arguments. They found that the likelihood that a firm has an explicit call option to acquire equity in an IJV is a function of property rights, political, and diversification-related uncertainty, but not of cultural distance between partners' home countries – though only a very small proportion of JV listed in their sample, drawn from the SDC database, had explicit options (1% in general, and 4% of minority holdings). Altogether, there is some support for the premise that JVs serve as ROs (Kogut, 1991; Chi & McGuire, 1996; Reuer, 2000, 2002; Reuer & Leiblein, 2000) – albeit mostly implicit ROs. Further research in this area is thus warranted.

Researchers have also examined the governance implications of implicit and explicit ROs. Chi (2000) and Reuer and Tong (2005) argued that explicit call options in JVs are one of several contractual safeguards that can be used to reduce transaction costs. More specifically, Reuer and Tong (2005) argued that an explicit call option enables a firm to take control of a JV when it observes that its partner is cheating (for instance, misappropriating knowledge), or alternatively that the presence of an explicit call option might reduce the chance of such opportunistic behavior. However, Chi and Seth (2002) and Seth and Chi (2005) argued that the presence of an explicit call option may weaken the other party's incentive to contribute to the JV beyond the value of the strike price of the option, as all value resulting from these additional contributions will be captured by the call option holder. Put together, these arguments suggest important questions for future research. Would monitoring the other party in a JV with an explicit call option clause, in order to know when to strike the option and take control of the venture, be subject to greater or lesser costs and constraints than without an explicit option clause – and under what conditions? More generally, how would negotiation and monitoring costs compare, considering the stages identified above – from initial JV setup to potential renegotiation to option exercise or other JV conclusion? Before turning to the later stages, we examine another critical initial decision regarding JVs as ROs – namely, the initial distribution of equity shares among JV partners.

THE INITIAL DISTRIBUTION OF EQUITY AMONG JOINT VENTURE PARTNERS

Real Option Theory

Several scholars have examined the initial formation of JVs from an RO perspective (e.g., Chi & McGuire, 1996; Folta, 1998). One key finding is that the options embedded in JVs will have an impact on the distribution of the equity stakes. On the one hand, an investor who tries to capture the static NPV part will take an as large as possible share in the JV, to fully capture the JV's future cash flows. In the extreme, this will lead to an acquisition instead of a JV (Seth & Kim, 2001). On the other hand, an investor who aims to capture the dynamic RO part will invest in a smaller share of the JV because this way (s)he limits the downside risk while preserving the opportunity to capture the upside potential (Chi & McGuire, 1996; Reuer, 2002).

The value of the dynamic option part is a function of the same five factors that determine the value of financial options, i.e., the value of the underlying asset, the strike price, the time to maturity, the risk-free rate and the uncertainty surrounding the underlying asset (Seth & Kim, 2001). Of these, uncertainty has been by far the most prominent throughout the RO literature on JVs, because of its natural appeal to strategy and international business scholars.

Chi and McGuire (1996) argued that the value of the options embedded in JVs is positively related to market, partner-related, and legal uncertainty. Hence, higher levels of uncertainty in general, and these three forms of uncertainty in particular, should lead to investors taking a smaller share in JVs. Using a sample in the biotechnology industry, Folta (1998) studied the tradeoff between administrative control and commitment. He found that uncertainty about the partner, exogenous technological uncertainty, and competitive uncertainty all influence the likelihood of choosing a collaborative venture over an acquisition. However, when a distinction was made between two types of collaborative ventures – minority investments and JVs – the results showed that only exogenous technological uncertainty encouraged the formation of JVs as call options (rather than acquisitions). Multiple forms of uncertainty were associated with taking RO positions in the form of minority equity investments (rather than acquisitions).

In order to explain the apparent inconsistencies found in past research (e.g., Folta, 1998; Reuer & Leiblein, 2000), Cuypers and Martin (2006b, 2006c) sought to refine and expand conceptually and empirically the boundaries of RO theory, with application to the ownership distribution of JVs. They built on the distinction between forms of uncertainty that resolve endogenously and exogenously (Roberts & Weitzman, 1981): Exogenous uncertainty is uncertainty of which the resolution is unaffected by the actions of the firm, while endogenous uncertainty is resolved (at least partially) by the actions of the firm itself over time.[6] Cuypers and Martin (2006b, 2006c) theorized that only exogenous uncertainty would have the impact suggested by RO theory. The case of exogenous uncertainty corresponds to models of financial options, where it is assumed that uncertainty is resolved independently of the investor's behavior. Moreover, Dixit and Pindyck (1994) argue that exogenous uncertainty increases the value of waiting for new information and makes committing resources early less attractive, because investing will not influence how uncertainty is resolved. Hence, RO models should be applicable.

However, when uncertainty resolves endogenously, RO logic is subject to three objections. First, because investors are no longer price-takers, conventional option valuation models break down. Second, firms will have an incentive to invest and commit resources rather than wait (Dixit & Pindyck, 1994). Third, the flexibility of targets renders RO theory problematic as a decision-making template (Adner & Levinthal, 2004). For these reasons, RO predictions will not accurately describe firms' responses to endogenous uncertainty.

Using a sample of 6,472 Sino-foreign JVs established between 1979 and 1996, Cuypers and Martin (2006b, 2006c) found, as predicted by RO theory, a negative relationship between the initial equity share taken by the foreign partner and three sources of exogenous uncertainty: economic conditions, local institutions, and exchange rate fluctuations. Conversely, they found no such relationship for three sources of endogenous uncertainty: cultural uncertainty, uncertainty resulting from the scope of JV operations, and technical uncertainty associated with product development activities. Indeed, null hypothesis tests showed that these endogenous sources of uncertainty have no significant effect on the distribution of equity shares among partners. In summary, Cuypers and Martin (2006b, 2006c) theorized and showed empirically that initial alliance governance decisions, as evidenced by initial equity stakes in IJVs, conform to RO predictions when uncertainty is exogenous but not when uncertainty is endogenous. Furthermore, they provided a first empirical test, which is more consistent with Chi and McGuire's (1996) model by considering the entire range of the ownership distribution rather than just the choice between collaborative ventures and acquisitions, or minority and majority JVs.

Alternative Theories

A number of other theories have been used to study the initial formation of JVs – for an overview of these, see Cuypers and Martin (2006a). This raises the question of whether and how these theories contradict or complement RO theory. Next, we briefly discuss three alternative approaches that have been used to examine governance decisions including the distribution of JV equity shares.

Transaction Costs Economics (TCE)

Transactions are arrayed on a continuum between markets and hierarchy. On this continuum, the optimal degree of integration (control) reflects the trade-off between shirking costs that tend to arise when the parties are brought into the same organization and cheating costs due to opportunism by arm's length parties (Williamson, 1985; Hennart, 1993). In TCE, behavioral uncertainty figures as an endogenous factor that can be addressed via governance decisions. Furthermore, exogenous uncertainty acts in TCE theory as a conditional factor: It exacerbates other characteristics of the transaction (especially asset specificity) that increase ex ante and ex post costs of contracting (e.g., Williamson, 1985; Leiblein, Reuer, & Dalsace, 2002; Lu &

Hébert, 2005).[7] However, few TCE studies have examined JV equity shares. Furthermore, these studies have yielded mixed results regarding uncertainty – especially regarding exogenous uncertainty.

Gatignon and Anderson (1988) studied the choice between full ownership and shared ownership, and the ownership level in case of shared ownership. They argued that higher levels of control, through equity ownership, are preferred in case of higher asset specificity – especially in combination with external (exogenous) uncertainty. Although R&D intensity, advertising intensity, and marketing asset specificity, were indeed all associated with a preference for full ownership, the interactions between them and external uncertainty were insignificant. Furthermore, Gatignon and Anderson (1988) were generally unsuccessful in explaining intermediate levels of ownership when ownership is shared. Similarly, Chen, Hu, and Hu (2002) failed to find a significant relationship between R&D and advertising intensities, respectively, and intermediate levels of ownership.

Delios and Beamish (1999) focused mainly on the nature of the resources that the foreign firm contributes to the IJV and argued that as asset specificity increases, the foreign firm will take a higher equity position in order to reduce the increased hazards of opportunistic behavior by the other party. However, their results suggest ambiguous effects of transactional characteristics on the ownership distribution of IJVs.

Bargaining Perspective

The ownership distribution of a JV is the outcome of negotiations in which relative power is a deciding factor (Fagre & Wells, 1982). Generally, it is assumed that partners prefer full ownership to gain more control and greater payoffs from the venture. Subsequently, the relative bargaining power between both parties explains deviations from full ownership. However, the preferred ownership structure predicted by other theories could also serve as a starting point and the bargaining power of the venture's parties can then be used to explain deviations from the starting point (Blodgett, 1991).

A wide range of factors seem to influence bargaining power, and thereby the equity distribution (Kobrin, 1987). Fagre and Wells (1982) found a partner's level of ownership to be positively related to its advertising intensity, its provision of market access, and the amount of technology that it contributes; and negatively related to its number of competitors. Blodgett (1991) found that partners who contribute technology tend to have a higher initial share in the JV, in particular when the other party only contributes local knowledge and marketing resources. Furthermore, government restrictions may limit the bargaining power of the foreign party by restricting the range of ownership it can bargain for (Blodgett, 1991). However, the exogeneity of uncertainty-causing factors such a government regulation is not addressed in the bargaining perspective, which tends to focus on firm-level determinants of bargaining power.[8] In general, bargaining power seems to be negatively related to the need for complementary assets from the other party, and positively related to the contribution the firm makes to the JV.

Agency Theory

The ownership structure of companies influences agency costs, i.e., those inefficiencies resulting from the differing objectives of separate parties (Jensen & Meckling, 1976). Foreign partners depend on the effort of the local partner to make the JV succeed. However, the local partner only has an incentive to put effort into the JV to the extent that it receives benefits for its contribution. These benefits, in turn, are proportionate to the ownership share that the local partner holds since the distribution of profits of the JV is typically based on the ownership distribution of the JV. Hence, the local partner's effort will depend on the share in the JV it owns. The foreign partner can reduce the resulting agency costs by taking a smaller share in the venture (Nakamura & Yeung, 1994). Therefore, uncertainty about the behavior of the other party in the JV is endogenous. However, the foreign partner also has to avoid spillovers to potential competitors, in particular of intangible assets, by protecting the property rights of its resources. Nakamura and Yeung (1994) argued that the likelihood of such spillovers decreases less than proportionally as the foreign partner's share in the JV increases. Using data on technology-based US subsidiaries in Japan, they found, as predicted, that JV ownership share is determined by a combination of spillover and agency considerations. Furthermore, they reported ownership differences across different industries, which they attributed to differences in the level of reliance on intangible assets – which is endogenous – rather than an exogenous industry condition.

Chi and Roehl (1997) distinguished between ownership level and control in JVs. More specifically, they argued that cheating cost could be reduced by means of more control – measured by the number of key managerial positions held in the venture. Shirking costs, on the other hand, can be reduced by giving away more of the venture's payoff – measured by the level of equity ownership. Such shirking costs depend on how important and measurable a party's effort is to the overall success of the venture. Chi and Roehl (1997) found positive relationships between the amount of discretionary training provided by the foreign partner, the proportion of JV output distributed by the foreign partner, and the dissimilarity between the local and foreign partner, respectively, and the foreign partner's equity share. This indicates that the initial ownership distribution serves to align incentives when one party's expected contribution is important to the overall performance of the venture yet is hard to measure, rather than to increase control and thereby reduce the costs of making specific investments. Thus, Chi and Roehl (1997) described how sources of endogenous uncertainty affect equity shares. It is noteworthy that these sources of uncertainty can be controlled by the partners. However, this research did not address exogenous uncertainty.

Conclusion

Several theoretical perspectives besides RO theory can be used to study the formation of JVs (see Table 1). Furthermore, based on the above discussion, we can identify areas of overlap and complementarity with these perspectives. First, TCE and agency theory focus primarily on behavioral uncertainty, which is endogenous. These theories have contributed to the analysis of endogenous uncertainty as it affects JV equity share. However, they have not yielded strong generalizable results regarding exogenous uncertainty. This may be because, in TCE theory, exogenous environmental uncertainty is of interest not as a direct effect but as an interactive effect (and likewise, more implicitly, in agency theory). With respect to exogenous uncertainty, which we know to influence equity shares too, RO theory has proven itself to be a most promising starting point (Folta, 1998; Cuypers & Martin, 2006b). Thus, theoretical arguments and the empirical evidence in the literature dedicated to each theory suggest that TCE and agency theory hold promise as complements to RO theory, with RO theory shedding light on exogenous uncertainty (Cuypers & Martin, 2006b, 2006c), while the other theories shed light on endogenous uncertainty (Cuypers & Martin, 2006a).[9]

Second, studies from a bargaining perspective have provided limited insight into exogenous uncertainty. Still, this perspective may complement RO theory, as follows: The exercise of bargaining power might explain some deviations in initial equity shares relative to what RO theory would indicate. Given that no empirical study has touched upon this, it remains unclear whether or not, and in which direction, relative bargaining power can actually explain deviations from the initial ownership distribution predicted by RO theory. This too represents an opportunity for future research.

In this section, we have highlighted the need for – and rewards from – a more precise conceptualization of uncertainty when studying the initial distribution of equity among JV partners. There is a fundamental difference

Table 1. The Initial Distribution of Equity among Joint Venture Partners: A Comparison of Perspectives.

Theory/Approach	Unit of Analysis	Focus (Goal Assumed)	Predicted Effects on Initial Equity Share Taken by the Focal (Foreign) Partner		Selected Studies[a]
			Exogenous uncertainty	Endogenous uncertainty	
Real option theory	Option, i.e., an investment sequence	Investment value maximization via downside risk minimization	Direct effect, negative	No effect	Chi and McGuire (1996), Cuypers and Martin (2006a, 2006b, 2006c), Folta (1998)
Transaction cost economics	Transaction	Transaction cost minimization	Conditional effect (positive moderation)	Direct or conditional (positive moderation) effect	Chen et al. (2002), Delios and Beamish (1999), Gatignon and Anderson (1988)
Bargaining perspective	Firm dyad (or firm-government dyad)	Maximization of the share of benefits (relative to the partner)	Mostly ignored	Bargaining power, obtained via control over resources and uncertainty, is positively associated with initial ownership share.	Blodgett (1991), Fagre and Wells (1982), Kobrin (1987)
Agency theory	Principal and agent	Agency costs minimization and effort maximization	Mostly ignored	Direct effect, depending on shirking vs. spillover or cheating costs	Chi and Roehl (1997), Nakamura and Yeung (1994)

[a]All studies listed in the table are discussed in the text above.

between endogenous uncertainty and exogenous uncertainty. This calls for a more explicit and elaborate argumentation as to what theory, or combination of theories, is suitable given the sources of uncertainty on hand. TCE and agency theory hold promise as complements to RO theory. Furthermore, the bargaining perspective may be useful to explain some deviations from normative RO models. Many of these insights, starting with the importance of conceptualizing uncertainty carefully, also stand to be relevant in studying later JV stages from an RO perspective. Given this, we turn next to the stability and change in JVs following their formation.

THE STABILITY AND EVOLUTION OF JOINT VENTURES

Real Option Theory

Another aspect of JVs that has received attention from an RO perspective is the stability of JVs after their formation. JV instability – or more generally evolution – can refer to a number of different outcomes: joint or unilateral dissolution, termination of the JV, a partial change in ownership, a full buyout of one partner by the other, or (in rare cases) a (partial) sale to a third party. Each outcome may have different causes, as described below, but in all cases there is a change in the ownership and/or activity of the JV, which indicates a change in option terms and/or an exercise of the option.

According to RO theory, the holder of a (call) option will hold onto the option either until it expires, meaning that the joint activity ceases; or until a positive signal occurs, i.e., the value of the underlying asset exceeds the strike price at which the firm can increase its equity share. This discrete investment logic distinguishes an RO investment from other path-dependent and incremental investment processes (Adner & Levinthal, 2004).

Kogut (1991) examined the effect of demand uncertainty on the timing of the exercise of call options, when one JV partner buys out the other. Using a sample of 92 manufacturing JVs, he found that the timing of exercising the option is determined by positive product market signals, while negative signals do not affect the stability of the JV. This asymmetry in the effects of positive and negative signals, combined with the discrete nature of changes in ownership structure, is a defining characteristic of JVs as ROs.

Similarly, Miller and Folta (2002) and Folta and Miller (2002) studied the timing decision to exercise ROs. Miller and Folta (2002) argued that the optimal time to exercise real call options depends on six factors: (1) the current dividends, (2) the exercise price, (3) the residual resource value, (4) the discount rate, (5) the call option value, and (6) the nature of the option (compound vs. simple). In turn, they argued that most of these six factors are determined by a number of other factors.[10]

Folta and Miller (2002) examined empirically the timing decision to strike real call options embedded in biotechnology equity partnerships, by looking at the acquisition of additional equity by one party. They found that the value of the underlying asset and the number of parties in the JV increase, while the level of technological uncertainty decreases, the likelihood that an option is exercised. Furthermore, they looked at interaction effects and found that the effect of the value of the underlying asset, and the effect of the number of parties on the timing of striking the option, both differ under different levels of technological uncertainty. They also found some evidence, albeit weak, that the presence of an explicit option decreases the likelihood that options are struck. This result contradicted Miller and Folta's (2002) prediction.

Finally, Vassolo, Anand, and Folta (2004) studied empirically both the abandonment decision and the striking of options in collaborative ventures in the biotech industry. Consistent with RO theory, they found a negative relationship between industry uncertainty and the technological distance between the focal alliance and the parent's portfolio of other alliances, respectively, and the likelihood of the alliance being divested. Additionally, Vassolo et al. (2004) found evidence of a negative relationship between the technological distance between the firm and the focal alliance, and the likelihood of striking the option. However, they failed to find any such relationship for technological uncertainty. Like Folta and Miller (2002), they found that explicit option agreements decrease the likelihood of buyouts and divestures.

Alternative Theories

A number of other approaches have been used to explain alliance evolution and instability (Gulati, 1998). Most prominent among them are transaction cost economics, the bargaining perspective (power dependence), and organizational learning and experience (Martin et al., 1994).[11] In addition, there are large differences across and within these approaches in the way instability is defined or operationalized. These different operationalizations of instability each correspond to different outcomes from an RO perspective. On the one hand, several studies focused on JV termination as JV instability (e.g., Barkema & Vermeulen, 1997), which from an RO perspective, corresponds with letting options expire. On the other hand, some scholars studied partial or full buyouts (e.g., Balakrishnan & Koza, 1993), which from an RO perspective correspond with striking the option. Furthermore, some studies did not distinguish between both outcomes (e.g., Blodgett, 1992). We will now briefly discuss the theoretical approaches and findings most predominant in the literature: transaction cost economics, the bargaining perspective, and learning theory.

Transaction Costs Economics (TCE)

Although TCE is sometimes held to be a static theory that focuses on ex ante governance decisions, Williamson (1991) argued that TCE can be the basis of a comparative analysis that explains the adaptation of governance structures – and specifically JVs – to changing circumstances. Following this line of reasoning, some studies have examined the postformation dynamics of JVs from a TCE perspective. Lu and Hébert (2005) argued that the survival of a JV depends on the fit between the initial conditions, i.e., the characteristics of the transaction and the environment, and the chosen governance structure at the formation of the JV. They found that higher levels of control in IJVs in the presence of high asset specificity (i.e., fit between governance arrangement and transaction conditions) lead to higher IJV survival rates. Reuer and Ariño (2002) also studied the impact of the initial conditions of JVs on their stability, as measured by the absence or presence of a contractual renegotiation. They argued and found that the willingness or the ability to change the governance of alliances increases with the level of governance misfit and asset specificity while it decreases when there are more contractual safeguards. Furthermore, they examined whether or not changes in the environment affect the decision to renegotiate. They did not find any effect of changes in the environment on this form of JV stability.

Bargaining Perspective

Earlier studies, which linked the internal structure of JVs to their stability, argued that ventures with a dominant partner were more stable. Absolute control makes it easier to make decisions and the potential for conflict will be reduced (Killing, 1983). However, subsequent research argued and found empirical evidence that a more equal ownership division will result in more stable JVs (e.g., Beamish & Banks, 1987; Blodgett, 1992; Hennart & Zeng, 2002). As discussed above in the section covering the formation of JVs, this stream of research sees the ownership of a JV as the result of the relative bargaining power of the partners in the negotiation process. Balanced ownership indicates partners with equal bargaining power and equal contributions to the JV, which pushes both partners to make accommodations that enhance stability. Conversely, an unequal ownership division implies that one partner has made a larger contribution to the venture and has more bargaining power than the other party, which it can use to dictate terms, leading to more negotiations and changes (Blodgett, 1992).

Some studies have taken a more dynamic perspective by focusing on shifts in bargaining power (e.g., Inkpen & Beamish, 1997). Such shifts can be the consequence of learning or changes in the environment (Hamel, 1991). Hamel (1991) and Inkpen and Beamish (1997) argued that learning is the more important determinant of changes in relative bargaining power and JV instability. Hence, there is an overlap between this dynamic bargaining perspective and the view of JVs as learning races (which we discuss below) in that as knowledge is acquired from the partner, the dependence of one party on the other is reduced and the likelihood that the JV is terminated increases. Yan and Gray (1994) found that changes in the environment, such as policy changes introduced by local governments, also lead to changes in relative bargaining power between the partners and thereby trigger changes in the structure of the venture.

Learning Theory

Kogut (1988) argued that JVs are vehicles to learn and transfer knowledge. Subsequently, learning from past collaborative ventures and learning within collaborative ventures will have an impact on their stability. The literature includes studies that stipulate three very different learning purposes, and thereby different links between learning and stability: learning about partnering, learning from the partner, and learning about the partner.

First, several studies have examined the effect of *prior experience* on the survival of JVs. However, different scholars have put forward opposing effects of prior experience on JV survival. On the one hand, several scholars have argued that prior experience will lead to more stable JVs. For instance, Barkema et al. (1996) and Barkema and Vermeulen (1997) found that the cultural barriers associated with starting a venture abroad are reduced as a result of learning from prior experiences abroad, which increases the survival of foreign collaborative ventures. Furthermore, Pangarkar (2003) argued and found evidence that collaborative ventures will last longer if both partners have prior experience because firms learn to manage alliances and generate synergies through the pooling of resources. On the other hand, some researchers have argued that prior experience would lead to more unstable JVs. Blodgett (1992) found that prior experience in the renegotiation of ownership terms would lead to more unstable JVs because partners learn to make similar changes in the future. Reuer, Zollo, and Singh (2002) integrated these two opposing effects on the stability of JVs. They argued that experienced firms should be able to design the JVs more effectively ex ante, which increases JV stability; while prior experience also creates a capability to effectively modify the alliance's governance structure, which decreases JV stability. By discriminating between different types of experiences in which different effects dominate, they found support for their arguments. The corresponding form of instability is a change in the terms and equity shares in the JV.

Second, a few studies have examined the competitive learning dynamics of partners within JVs. Firms may enter into a JV with the aim of learning and internalizing the skills of its partner. In that case, collaborative ventures can be seen as a transitional device in which partners race or compete to learn and acquire each other's resources, competencies and skills. As soon as one partner has achieved its goal, the race is over and the JV will be terminated (Hamel, 1991). Thus, the timing of the termination of the JV will be a function of the pace of learning, which is endogenous to the partners' actions according to Hamel (1991). Furthermore, the termination of JVs will be the likely outcome observed, and such termination represents a success for at least one partner from this perspective. However, the prevalence of such strategies is in question. Hennart, Roehl, and Zietlow (1999) failed to find support for the associated prediction that firms specifically the Japanese firms discussed by Hamel (1991) – use JVs as temporary "Trojan horses" at the expense of their partners. Because of the importance of relation-specific skills and routines, stability in interfirm cooperation is in fact normally a precondition both for partner expansion and for knowledge sharing among partners, and these in turn reinforce the stability of interfirm relations (Martin, Swaminathan, & Mitchell, 1998; Kotabe, Martin, & Domoto, 2003).

Third, making use of learning and information economics arguments, Balakrishnan and Koza (1993) argued that JVs could act as intermediate forms that enable firms to learn about possible takeover targets. A firm can use the JV as a means to collect information about the quality of its partner. Subsequently, if the partner turns out to be of bad quality the JV will be terminated. Conversely, if the partner turns out to be of good quality an acquisition will take place. Several subsequent studies have argued or found empirically that JVs can mitigate the effect of information asymmetry about a potential acquisition target (Reuer & Koza, 2000; Shen & Reuer, 2005). Thus, the corresponding form of JV instability is the effective buyout by one partner as it acquires the other partner, and suggests potential success for both partners.

Conclusion

In this section, we compared the literature used to explain the evolution and stability of JVs (see Table 2). The TCE literature on JV stability is still small and has mainly focused on how the degree of fit between the initial conditions and the governance choice at the formation stage influences subsequent stability. Nevertheless, TCE holds promise to shed light on endogenous uncertainty too. As we have described earlier, environmental uncertainty has an interactive effect from a TCE perspective (Williamson, 1985). Namely, a change in environmental conditions will not have much of an impact unless some other characteristics of the transaction, such as a high level of asset specificity, make this change problematic. Meanwhile, RO theory points to the existence of an explicit option, depending on uncertainty, as factors affecting JV stability. Thus, TCE and RO theory do not contradict each other. However, the interaction effect between environmental changes and asset specificity has not been tested empirically in the context of JV stability. Furthermore, it would imply a realignment of ownership shares. From an RO perspective, however, equity stakes adjust asymmetrically – specifically, the holder of a call option will increase her share only if changes in the environment push the option "in the money", i.e., if the value of the partner's underlying equity share has improved beyond the threshold strike price. Therefore, we propose:

Proposition 1a. Ceteris paribus, the likelihood of JV instability will increase when there is a change in the environment and there is high asset specificity.

Proposition 1b. Ceteris paribus, in the presence of an explicit call option, this effect will be stronger on the likelihood of a (partial) buyout (as opposed to termination), but only if the change in the environment pushes the JV share's value beyond the strike price.

The bargaining perspective has been used to predict both the initial distribution and subsequent changes in bargaining power. On the one hand, the studies looking at the initial bargaining power distribution argued that more unbalanced bargaining power, which translates in a more unequal equity division, will result in more unstable JVs. However, RO theory offers an alternative explanation for this prediction. Namely, taking an RO position will correspond to taking a smaller share in a JV with the intention to change this equity position at a later stage. Thus, a more imbalanced equity position might lead to JV instability from an RO perspective because it corresponds with one party taking an option. Furthermore, in the case of an

Table 2. The Stability of Joint Ventures: A Comparison of Perspectives.

Theory/Approach	Unit of Analysis	Focus (Goal Assumed)	Predicted Effects on JV Stability		Selected Studies[a]
			Exogenous uncertainty and change	Endogenous uncertainty and change	
Real option theory	Option, i.e., an investment sequence	Maximize return by increasing investment under positive ex post conditions but not under negative ex post conditions	Changes in value have direct asymmetric effects: buy out partner if option is in the money; else hold on to the option, or terminate the option (divest) if an option-based divestment threshold has been reached Exogenous changes also determine the timing of option exercise	No effect	Kogut (1991), Folta and Miller (2002), Miller and Folta (2002), Vassolo et al. (2004)
Transaction cost economics	Transaction	Minimize the misfit between the governance arrangement and the transaction conditions	Conditional effect (close or renegotiate JV in case of misfit)	Direct and/or conditional effect (close or renegotiate JV in case of misfit)	Lu and Hébert (2005), Reuer and Ariño (2002)

Bargaining perspective	Firm dyad (or firm-government dyad)	As power is gained or lost, exert it accordingly to maximize share of benefits from the JV (relative to the partner)	Changes in power have direct symmetric effects (the effect of a gain in power is the reverse of the effect of a loss of power)	Changes in power have direct symmetric effects (the effect of a gain in power is the reverse of the effect of a loss of power)	Blodgett (1992), Inkpen and Beamish (1997), Yan and Gray (1994)
Learning theory	Partners	Use learning to enhance the performance of the JV or the returns from the JV to the parent	No effect	Direct effects: Learning about allying affects JV survival and renegotiation; Learning from partner affects JV continuation; Learning about partner affects partner acquisition	Barkema, Bell, and Pennings (1996), Hamel (1991), Pangarkar (2003), Reuer and Koza (2000), Reuer et al. (2002), Shen and Reuer (2005)

[a]All studies listed in the table are discussed in the text above.

option, the timing and conditions for a change in equity shares should correspond to specific changes in business conditions whereby the option becomes "in the money."

On the other hand, several studies argued that shifts in bargaining power would result in JV instability. Furthermore, the emphasis in these studies is on internal and endogenous factors, such as learning, which influence bargaining power. Chi and McGuire (1996) and Chi (2000) suggested that this bargaining power argument and RO theory might be complementary. Specifically, they argued that bargaining power would affect the value distribution between the parties in a changing JV, in case a strike price has to be negotiated when there is no explicit call option. Consequently, the parties in a JV would anticipate shifts in bargaining power and react by negotiating for an explicit option clause. Accordingly, the following proposition can be tested:[12]

Proposition 2a. Ceteris paribus, the likelihood that a firm has an explicit call option will be higher when it expects its bargaining power to deteriorate during the life of the JV.

However, when there is no explicit option in place we would expect the option holder to anticipate a loss in bargaining power by striking the option when (s)he still has a more favorable level of relative bargaining power. This way, the option holder is able to capture more value than after the shift in bargaining power. Hence, we expect the following effect of shifts in bargaining power on the timing of exercising the option:

Proposition 2b. Ceteris paribus, the likelihood that the holder of an implicit call option will increase its share or buy out its JV partner is higher when the holder expects that its bargaining power will deteriorate, while such a relationship will not hold when the option holder has an explicit option clause.

Although external factors have received less attention from a bargaining perspective, they may also play a significant role in explaining shifts in bargaining power and subsequent JV instability. Similarly, RO theory predicts that favorable changes in the environment results in option holders exercising their options. Thus, both the bargaining perspective and RO theory seem to offer similar predictions for favorable changes in the environment. However, RO theory predicts that JVs will remain stable when the changes in the environment are unfavorable until the expiry date of the option. Thus, the predictions of both views differ when it comes to changes that have a negative impact.

Beside the learning race view of JVs, the learning perspective has focused on prior experience. On the one hand, prior experience is expected to influence the ability to design alliances ex ante and the ability to restructure the alliance ex post, and thereby influence JV stability. However, this view only focuses on ability and not on the external factors that would trigger the need for ex post adjustments. Hence, this part of the learning literature on alliances does not seem to contradict or overlap with RO theory. Some studies have also explored how learning can reduce uncertainty during the life of JVs. These studies hold promise as complements to RO theory, with RO theory shedding light on the effect of changes in exogenous uncertainty (Cuypers & Martin, 2006c) while learning models focus on the impact of changes in endogenous uncertainty on JV stability.

Overall, the key feature of ROs, which distinguishes RO theory from the other theories described above, is the asymmetry in the expected effect of a negative and positive signal from the environment. Instability in the sense of one partner buying out at least a part of the other's share, will only occur after a positive signal is observed, while JVs are expected to remain stable when a negative signal is observed until the option expires. This property of ROs should be exploited, as done by Kogut (1991), to distinguish empirically between RO explanations and alternative explanations such as the bargaining perspective and learning theory. Furthermore, we showed how the bargaining perspective could contribute to our understanding of the timing of exercising options, and vice versa. Namely, changes in relative bargaining power due to asymmetric learning are likely to be a key determinant of the timing decision to strike options when no explicit option clause is present, but this effect will depend on the existence of an explicit option as well as the direction of changes in environmental conditions.

PERFORMANCE

There exist a variety of ways to assess performance in the JV literature (Anderson, 1990; Olk, 2002). First, there are a number of alternative levels of analysis. The performance of the JV itself can be analyzed, or that of one specific parent, or the combined performance of all parents. Second, performance can be measured via several scales such as subjective evaluation and satisfaction, financial performance, or JV (or parent) survival. Third, performance can be measured at different points in time, and over different time horizons. For instance, regarding financial performance, abnormal returns from event studies capture all performance implications of an investment as they can be anticipated in a near-instantaneous measurement window, while accounting measures such as ROA capture performance as it unfolds during the selected years. Likewise, there exist a broad range of measures of performance in the RO literature, as reviewed by Reuer and Tong (2007).

Most RO studies at least implicitly assume that investment decisions made in accordance with RO predictions will lead to value creation and higher financial performance (Kumar, 2005). However, studies testing this assumption are few, particularly pertaining to JVs. Kumar (2005) provided insights into the conditions under which acquiring a venture – i.e., striking a call option – or divesting a venture enhances the value of the parent firms. Using event study methodology, he found that JVs created value when they were divested with the aim of refocusing the firm's product market portfolio. Furthermore, the results revealed a negative relationship between the value created by both the acquirers and divesters, respectively, and the degree of technological and demand uncertainty. A similar relationship was found between the degree of rivalry in the target market and the value created by the acquirer. Contrary to RO predictions, rivalry did not seem to influence the value created by the divester. Furthermore, Kumar (2005) failed to find positive abnormal returns when a partner acquired a JV with the aim of growth and expansion in a target market, which would be predicted by RO theory.

Tong, Reuer, and Peng (2007) also examined under what conditions firms capture growth option value from having JVs. Contrary to Kumar (2005) who used abnormal returns to measure option value, Tong et al. (2007) measured value creation at a more aggregate corporate level. Namely, they partitioned the total value of the firm into a "value of assets in place" component and a "growth option" component, as suggested by Myers (1977). Their findings revealed a positive relationship between a firm's number of JVs and its growth option value. Furthermore, they found that the number of minority JVs and the number of non-core JVs have a greater impact on growth option value than the number of non-minority JVs and the number of core JVs, respectively. This is consistent with JVs being valuable growth options. However, they failed to find that the number of JVs in developing countries has a greater impact on growth option value than the number of JVs in developed countries.

Finally, Reuer and Leiblein (2000) focused on the value that results from using ROs to limit downside risk, rather than on the upside potential of making RO investments. This is important as Kogut (1991) argued that firms could use JVs to capture upside potential by buying out a partner when favorable news becomes available, while limiting their downside risk.

However, inconsistent with this RO prediction, Reuer and Leiblein (2000) found that firms that enter into multiple JVs do not thereby reduce their downside risk. In fact, for two out of three measures of downside risk, IJVs were associated with increased risk.

In sum, although some of the above empirical findings offer support to some RO arguments, they also point out some important deviations from the predictions of the theory. Therefore, the performance implications of making RO investments should receive additional attention. Specifically, the conditions under which JVs indeed serve as growth options that enhance firm value require attention. So do the conditions under which JVs do or do not allow firms to avoid downside risk.

The conditions under which JVs serve as growth options can be studied by combining elements of Kumar's (2005) and Tong et al.'s (2007) approaches and looking at the effect of divestments and buyouts on a firm's growth option value. The adjustment to a firm's growth option value after a divestment or buyout will depend on the conditions surrounding the JV, specifically the level of exogenous uncertainty that enhances the growth option. Accordingly, we propose:

Proposition 3a. Ceteris paribus, divesting a JV surrounded by higher levels of exogenous uncertainty will lead to a higher reduction in a firm's growth option value than divesting a JV surrounded by lower levels of exogenous uncertainty.

Proposition 3b. Ceteris paribus, buying out a JV surrounded by higher levels of exogenous uncertainty will lead to a higher reduction in a firm's growth option value than buying out a JV surrounded by lower levels of exogenous uncertainty.

INTEGRATING THE DIFFERENT STAGES OF JOINT VENTURES

As we have discussed earlier, one of the attractive features of RO theory is that it is a dynamic perspective that can explain each of a JV's life-cycle stages – from initial conditions, to JV terms and initial ownership, to formation, to subsequent adjustment and post-JV outcomes (sale, dissolution, etc.). Ideally, such a dynamic theory requires consistency in researching sequential stages. However, some variables or relationships that have been studied at one particular stage of JVs have received far less attention (or none at all) in studies that examined other stages. In this section we aim to integrate the different JV stages from an RO perspective. We discuss each of the stages and recap the results and arguments stepwise. Based on this we develop implications and propositions for researching each subsequent stage of the JV life cycle. We start by discussing how uncertainty can predict outcomes of each of the JV's life-cycle stages and then we move through each of the later stages – explicit vs. implicit options, initial equity shares, and finally stability and adjustments – to see how each of them can explain the subsequent stages. Table 3 describes the arrangement of the resulting predictions.

Exogenous Uncertainty

One of the most prominent concepts in RO theory, uncertainty, stands to influence each of the stages in the JV life cycle. As discussed above, Cuypers and Martin (2006b, 2006c) theorized and found empirically that exogenous uncertainty will affect the initial ownership distribution in JVs as predicted by RO theory, but endogenous uncertainty will not. Studies looking at the other stages in the JV life cycle have not explicitly contrasted the effects of two or more sources of uncertainty, nor distinguished between forms of uncertainty that resolve endogenously vs. exogenously. However, the theoretical arguments of Cuypers and Martin (2006b, 2006c) can be generalized. The distinction between exogenous and endogenous uncertainty stands to matter not only to different forms of ROs (Roberts & Weitzman, 1981; Adner & Levinthal, 2004), but also across stages of JVs as analyzed from an RO perspective. Our arguments so far entail that RO logic can help explain each of other stages of the JV life cycle when uncertainty resolves exogenously, but does not operate the same way when uncertainty resolves endogenously. Accordingly, first, we expect the presence of an *explicit call option* to depend on the nature of uncertainty. Thus, we propose:

> **Proposition 4.** Ceteris paribus, the likelihood that a firm has an explicit option to acquire equity is positively related to the level of exogenous uncertainty surrounding the JV. However, from a real option perspective, we do not expect such a relationship for JVs surrounded by endogenous uncertainty.

This does not preclude the possibility that from a transaction cost perspective, the likelihood of an explicit option increases with endogenous uncertainty because of the governance properties of such an explicit option – as

Table 3. Integrating Research on the Different Stages of Joint Ventures.

		Independent Variables			
		Exogenous uncertainty	Explicitness of call options	Initial distribution of equity among JV partners	Stability of JVs
Dependent variables	Explicitness of call options	Proposition 4	–	–	–
	Initial distribution of Equity among JV partners	Cuypers and Martin (2006c)	Proposition 7	–	–
	Stability of JVs	Proposition 5	Miller and Folta (2002), Folta and Miller (2002), Vassolo et al. (2004)	Proposition 9	–
	Performance	Proposition 6	Propositions 8a and 8b	Proposition 10	Proposition 11

suggested by Reuer and Tong (2005). In this area, then, RO and transaction cost theories are not fully reconciled.

Furthermore, we would expect the effect of the level of uncertainty on the *stability of JVs* to be consistent with conventional RO predictions when uncertainty resolves exogenously, but not when uncertainty resolves endogenously:

Proposition 5. Ceteris paribus, a lower level of exogenous uncertainty will increase the likelihood of a buyout by the call option holder. However, from a real option perspective, we do not except such a relationship for endogenous uncertainty.

Kumar (2005) found, as predicted, that a negative relationship exists between the value created by both the acquirers and divesters, respectively, and the degree of technological and demand uncertainty. Although Kumar (2005) considered these two distinct sources of uncertainty, he did not contrast exogenous and endogenous sources of uncertainty. Following Cuypers and Martin's (2006b, 2006c) arguments, we expect *performance implications* to be consistent with conventional RO predictions when uncertainty resolves exogenously, but not when uncertainty resolves endogenously. Accordingly, we propose:

Proposition 6. Ceteris paribus, from a real option perspective, the value created for the acquirer and the divester when a JV is (partially) acquired will be negatively associated with the degree of exogenous uncertainty. However, from a real option perspective, we do not expect such a relationship for JVs surrounded by endogenous uncertainty.

Explicitness of Call Options

Having an explicit call option gives the option holder certainty over the price it will have to pay when it decides to strike the option. Conversely, when a firm does not have an explicit option contract, it will have to negotiate a price when it wants to strike the option. There will be costs as a result of bargaining, and the other party is likely to capture at least part of the value that otherwise would have fully gone to the call option holder; however, in the meanwhile, any disincentive to effort by the party not holding the explicit option may be reduced (Chi & McGuire, 1996; Chi, 2000).

With respect to *initial JV equity shares*, this implies that having an explicit call option clause ex ante will make the option more valuable relative to not having such a clause, because the option holder will be able to capture all residual value (see also Reuer & Tong, 2005); while the option holder may concede more initial ownership to the other party in order to obtain the call option (Chi & McGuire, 1996). In this case, the two effects work in the same direction, and an investor who takes an explicit RO position in a JV is likely to have a smaller initial equity share. Hence, we expect:

Proposition 7. Ceteris paribus, if a firm holds an explicit call option, it will take a smaller share in the JV than when it only has an implicit call option.

However, there is a complication in that the presence of an explicit option clause seems to be determined by the same factor, i.e., exogenous uncertainty, as the initial ownership distribution (Reuer & Tong, 2005). The presence of an explicit option clause may also act as a mediator because exogenous uncertainty influences the ownership distribution. Therefore, it would be interesting to decompose the total effect of exogenous uncertainty on ownership distribution into an indirect effect through the presence of an explicit option and a direct effect, and evaluate which effect is more important. A similar effort would also prove insightful for other stages of the JV life cycle as exogenous uncertainty influences each of them.

The RO literature on *JV stability* has already largely incorporated the effects of explicit call option clauses. As discussed above, Miller and Folta (2002) argued that an explicit option clause accelerates the timing of striking options. Furthermore, Folta and Miller (2002) and Vassolo et al. (2004) controlled for the presence of explicit option clauses. However, both studies found that the presence of an explicit option clause decreases the likelihood of the option holder striking the option. Thus, the empirical results contradict Miller and Folta's (2002) prediction. This indicates a need for further research.

With respect to the *performance* implications of striking an option, the presence of an explicit call option is also relevant. As mentioned earlier, in the presence of an explicit call option the option holder will capture all value while in the absence of such a clause, the value is likely to be divided between the acquirer and divester. Hence, we expect:

Proposition 8a. Ceteris paribus, if the acquirer of a JV share held an explicit call option initially, the abnormal return for the acquiring party will be positive while the abnormal return for the divesting party will not differ from zero.

Proposition 8b. Ceteris paribus, if the acquirer holds only an implicit call option, the abnormal returns for the acquiring and divesting parties will both be positive.

Initial Joint Venture Equity Shares

Investors who are aiming to make an option investment will take a smaller share in the JV because the payoff of the option increases as the stake of the investor in the JV decreases. Conversely, investors will take a larger share if they aim to capture the static NPV part (Chi & McGuire, 1996). Thus, a different ownership stake will indicate a different type of investment.

Regarding the *stability of JVs*, we would expect RO investments to be associated with higher levels of instability than more static investments in the NPV part. Given that both types of investments are associated with taking different levels of equity in a JV, the equity distribution should be a predictor of JV stability. Therefore, we propose the following, which to our knowledge has not been tested in RO research:

> **Proposition 9.** Ceteris paribus, the likelihood that a firm will (partially) buy out its partner after receiving a positive signal will be higher when it has a smaller initial stake in the JV.

The *performance* implications of having different levels of ownership have not been studied empirically, although Chi and McGuire (1996) developed a model whereby the payoff of striking the option increases as the initial stake of the investor in the JV decreases, because the investor has a greater range of additional in-the-money equity to invest in. Assuming that this relationship holds, we would expect the following:

> **Proposition 10.** Ceteris paribus, an acquirer that held a smaller share will have a higher abnormal return when it (partially) buys out its partner.

Stability of Joint Ventures

Tong et al. (2007) found a positive relationship between a firm's number of JVs and its growth option value. However, they did not study the effects of instability of the JVs in a firm's option portfolio on the firm's growth option value. Any adjustment in the number of options, should lead to a corresponding adjustment in growth option value. Three kinds of adjustments can be made: (1) terminating a JV, (2) fully buying out a JV, or (3) partially buying out a JV. All three should reduce the growth option value. However, the latter case should reduce growth option value less as it does not fully abandon or strike the option as in the first two scenarios because it leaves the possibility to acquire an additional stake in the future. Accordingly, we predict:

Proposition 11. Ceteris paribus, the termination of a JV, the full buyout of a JV and the partial buyout all reduce the growth option value of a firm. However, this reduction will be smaller in the case of a partial buyout.

Conclusion

In this section, we compared the literature used to explain the different JV stages and discuss how each stage can predict outcomes at subsequent stages (see Table 3). We contributed to the literature by identifying a number of important research opportunities resulting from the current lack of integration between these different stages. We offered a number of predictions and suggestions toward a better integration within the RO literature on JVs.

Furthermore, the lack of integration between the different stages raises a number of empirical issues. First, there are several potential sources of omitted-variable bias when a determinant of one JV stage is ignored in studying subsequent stages. For instance, exogenous uncertainty affects both the ownership structure of JVs (Folta, 1998; Cuypers & Martin, 2006c) and the stability of equity partnerships (Folta & Miller, 2002). Furthermore, we have argued that the ownership structure will also have an effect on the stability of JVs from an RO perspective. However, to the best of our knowledge, none of the JV stability studies from an RO perspective has controlled for the initial ownership distribution. By integrating the different stages in the RO process, and based on the propositions in this section, we aim to clearly indicate which factors should be controlled for in each of the different stages.

Second, a possible endogenous-selection bias arises when the different stages are not sufficiently integrated. Firms make RO investment choices based on environment conditions. Hence, their investment decisions are self-selected and endogenous (Shaver, 1998). However, studies of the performance implications of RO investments do not incorporate several of the factors that determine the initial RO investment choice. The conclusions drawn from these studies might be incorrect or incompletely generalizable in the presence of self-selection. We have discussed above how the conditions and decisions leading to each successive JV stage (uncertainty, explicit vs. implicit options, initial equity shares, and subsequent stability) should be considered when studying the performance implications of making RO investments. This should help ensure that variable omission and self-selection do not invalidate future research.

INTEGRATING BEHAVIORAL INSIGHTS IN THE REAL OPTION LITERATURE

Objective vs. Subjective Uncertainty

Several scholars have called to study the behavioral aspects of making RO investments (e.g., Bowman & Hurry, 1993; Kogut & Kulatilaka, 1994; Li, James, Madhavan, & Mahoney, 2007). Responding to this call, Miller and Shapira (2004) reported evidence of biases in decision makers' estimations of the value of options. However, other than that paper, studies of the behavioral aspects of making RO investments remain lacking, particularly so when it comes to exploring JVs. Therefore, we aim to contribute to the existing literature by making use of behavioral decision theory to offer new insights on how managers perceive uncertainty and ROs.

While uncertainty is one of the fundamental concepts in RO theory, the way it is described in the literature does not necessarily correspond with observed practice. RO theory has its roots in finance. Therefore, it is generally (at least implicitly) assumed that investors are rational and able to specify an accurate distribution of the expected returns of an investment ex ante (Leiblein, 2003). Accordingly, uncertainty is usually conceptualized and measured as being *objective*. However, in reality managers value options based on their *subjective* perceptions of uncertainty (e.g., Bowman & Hurry, 1993). Furthermore, studies have found only weak to moderate correlations between objective and perceptual measures of uncertainty (e.g., Tosi, Aldag, & Storey, 1973; Boyd, Dess, & Rasheed, 1993). Therefore, it is important to consider how uncertainty is perceived by decision makers to explain more accurately how they make RO investments, and to explain observed deviations from normative RO models. In the section that follows, the decision maker of interest would be the (potential) investor in a JV. Since the investor is usually a corporate entity, the discussion is subject to the usual caveat about generalizing from individual to group- or organization-level decisions.

Heuristics and Biases Influencing Real Option Decisions

It has long been established that managers cannot gather all possible information from their environment, due to limited attention and information processing capacities (Simon, 1955). As a result decision makers are not able to make complete or fully accurate representations of their complex environments on which their actions are based (Simon, 1955; March & Simon, 1958). Instead, decision makers rely on a number of heuristics, i.e., simplifying strategies or rules of thumb, to deal with complex and uncertain decision situations. Normally these heuristics are useful and effective, but sometimes they lead to severe and systematic errors that tend to be universal and predictable (Tversky & Kahneman, 1982a). Drawing on prospect theory, Miller and Shapira (2004) found evidence of systematic biases in the valuation of ROs, which they attributed to whether choices were framed as losses or gains. However, a number of other heuristics may also influence the valuation and the striking of options.[13]

Overconfidence and Control

First, decision makers tend to be *overconfident* about the judgments they make. In an experiment in which subjects were asked to set the lower and upper bounds of the expected returns of different investment alternatives, Fischhoff, Slovic, and Lichtenstein (1977) showed that the range of possible outcomes of investments is systematically underestimated. Similarly, Shapira (1995) argued that decision makers systematically ignore very low probability events, even when they could have significant consequences for the organization. Thus, only a part of the range of possible outcomes of an investment is considered. If so, decision makers will systematically underestimate the volatility of the value of a JV. This will in turn lead to a systematic undervaluation of the corresponding option.

Second, decision makers overestimate the *degree of control* they have over the outcome of their strategies. They also assume that if things do not go according to plan they can turn things around with additional effort, even if outcomes are exogenously determined in reality. Thus, decision makers tend to see exogenous uncertainty as being endogenous (Langer & Roth, 1975; Schwenk, 1984). This will result in different investment incentives than those associated with RO logic. Based on these two arguments we propose:

Proposition 12. Ceteris paribus, investors are prone to underinvest in real options and therefore take a larger than optimal initial share in JVs.

Anchoring

A third relevant heuristic is *anchoring*. Decision makers revise their judgment about the value of variables that are crucial to their decisions when new information becomes available. However, these adjustments are generally not large enough. Thus, the values of the decision variables are biased toward the decision makers' initial values (Tversky & Kahneman, 1982a). Likewise, decision makers' valuation of the call option in a JV during the holding period will be biased toward their initial valuation of the option at the time of the JV formation. They will perceive uncertainty to resolve slower or to a lesser extent than it actually resolves. As a result, options will be exercised or abandoned sub-optimally. Therefore, we propose:

Proposition 13. Ceteris paribus, relative to the RO ideal, investors in a call option in a JV are prone to buy out their partner too late or abandon the JV at the expiration date even if the option is "in the money" (i.e., the value of the JV exceeds the strike price).

Availability

A fourth one includes that decision makers assess the probabilities that events will occur by the ease with which occurrences of a similar nature can be thought of. This *availability* heuristic can also lead to biases. Some events seem to occur more frequently than others because they are easier to think of, even if they do not actually occur more frequently in practice (Tversky & Kahneman, 1982b). The probability of these more *available* events will be overestimated while that of *unavailable* events will be underestimated (Sherman, Cialdini, Schwartzman, & Reynolds, 2002). The availability or ease with which events can be recalled will depend on a decision maker's experience (Tversky & Kahneman, 1974). Indeed Calori, Johnson, and Sarnin (1994) found empirical evidence of experience having an effect on CEOs' cognitive representations of the environment. Therefore, we expect top managers' subjective perception of uncertainty, and thereby their valuation of options, to be dependent on their prior experiences. Accordingly, we propose:

Proposition 14. Ceteris paribus, the negative relationship between exogenous uncertainty and (initial) share in a JV will be influenced by the level of prior experience that makes the source(s) of uncertainty more salient to the investor.

Role-Related Effects

Furthermore, Ireland, Hitt, Bettis, and de Porras (1987) found evidence that perceived uncertainty varies across different management levels in the organization. They argued that managers at different levels of the organization would have different experiences and access to different types of information. Adner and Levinthal (2004) argued that actors at different levels of the organization would have different perspectives and incentives influencing option investment decisions. Furthermore, managers will focus selectively on different aspects of the environment, including uncertainty, which are more relevant to their functional specialty (Dearborn & Simon, 1958). Therefore, we expect:

Proposition 15a. Ceteris paribus, the negative relationship between the source(s) of exogenous uncertainty and (initial) share in a JV will be influenced by the level of the decision maker in the organization's hierarchy.

Proposition 15b. Ceteris paribus, the negative relationship between the source(s) of exogenous uncertainty and (initial) share in a JV will be influenced by the functional specialty of the decision maker.

Besides these individual-level factors, organizational-level, institutional, and country factors may also lead to biases or challenges to make RO decisions (e.g., Hurry et al., 1992; Adner, 2007). Accordingly, future research should also examine these factors. Finally, future research should also study how these systematic biases can be reduced to make more optimal RO decisions. A number of bias-reducing strategies and routines have been proposed in the literature. For instance, Janney and Dess (2004) identified guidelines such as ex ante specifying decision rules, separating the role of option writer and option exerciser, and making use of external auditors to access exit strategies, which can be helpful to offset biases. Therefore, it would be interesting to assess whether or not firms who have such strategies and routines in place make more optimal RO decisions, and if so what the conditions and costs of implementing such guidelines are.

Implications

To summarize, additional attention to behavioral decision theory can help to advance our understanding of how ROs are valued and managed. While Miller and Shapira (2004) focused on individuals' evaluation of possible losses and gains, we have examined biases in the assessment of uncertainty. More specifically, we identified a number of relevant heuristics and explained how they could lead to biases in the way uncertainty is perceived. These biases in turn will influence the valuation and management of options. Therefore, our insights are all the more relevant for managers aiming to make optimal RO decisions. Furthermore, we distinguished between subjective and objective uncertainty and pointed out the importance of this distinction for research.

CONCLUSION

This paper provides an extensive survey of the RO literature on JVs, which contributes to this body of work in three ways. First, we reviewed the RO literature and a number of oft used alternative theories. By highlighting similarities and differences between the different theories, we have found RO theory to be complementary in most cases. However, in some instances RO theory seemed to be overlapping with or contradicting other theories at first sight. Therefore, it is important for future research to integrate these theories by investigating and refining their respective boundary conditions, both theoretically and empirically. The study of strategic alliances in general stands to gain from such efforts.

In this paper, we have also highlighted the need for integrating the different stages of the JV's life cycle. In doing so, we indicated a number of gaps and contradictions in the RO literature on JVs. We outlined several opportunities for future research by incorporating explanatory variables in a particular stage that previously have only been used in the context of another stage. Addressing these issues empirically in future research will advance our understanding of RO theory, particularly with respect to JVs.

Finally, we have examined the behavioral aspects of making RO investments. By linking RO theory with behavioral decision theory, we hope to introduce additional realism in the use of ROs, especially JVs. This refinement is all the more relevant as it can inform researchers about how practitioners use or misuse ROs in practice.

Overall, we have demonstrated that RO theory is an important perspective to study JVs for researchers in strategy and practitioners, and opened avenues for further research both in combining RO research with other theories, and in integrating what we know about different JV decisions and stages. Given the promise demonstrated by RO research to date, but also the gaps and inconsistencies in existing models and results, further research on

JVs from an RO perspective is well warranted. The research areas and predictions presented here should inform such research.

NOTES

1. For a review of JV types, purposes and scope, see Pisano, Russo, and Teece (1988) and Martin (2002).

2. However, we believe that our arguments are also broadly relevant for other types of JVs, which face their own distinct sources of uncertainty. For instance, ventures for joint product introduction must deal with uncertainty concerning design acceptance by buyers and regulators, competitive reaction, etc. (Pisano et al., 1988; Martin & Mitchell, 1998).

3. An explicit option is a contractual clause that specifies the terms including the conditions under which additional equity can be acquired from a partner (Reuer & Tong, 2005). Chi and Seth (2002) provided an extensive overview of different option specifications. These include options with predetermined exercise prices, flexible or fixed termination dates, or a predetermined pricing mechanism.

4. The holder of a call (put) option has the right but not the obligation, to buy (sell) an underlying asset at the contractually determined strike price until (American option) or at (European option) a certain expiry date (maturity).

5. Option valuation models assume that it is possible to specify the probability distribution of the future value of an asset. Therefore, the concept of uncertainty used in RO theory is actually closer to what Knight (1921) refers to as risk. Nevertheless, we will refer to this as "uncertainty" as this is done throughout most of the literature.

6. Li et al. (2007) also touch upon the distinction between exogenous and endogenous uncertainty in their general review of RO research.

7. Williamson (1985, p. 59) emphasizes the conditional effect of exogenous uncertainty: "The influence of [exogenous] uncertainty on economic organizations is conditional. Specifically, an increase in parametric [i.e., exogenous] uncertainty is a matter of little consequence for transactions that are nonspecific." Leiblein (2003) concluded that empirical findings in the TCE literature are consistent with Williamson's (1985) argument that exogenous uncertainty has a conditional effect. A few studies have postulated a direct effect of exogenous uncertainty on make-versus-buy decisions, but reported mixed or inconsistent results (e.g., Walker & Weber, 1984, 1987).

8. Some studies in the bargaining power literature have looked at the effects of government restrictions on mode of entry. However, to our knowledge, they have focused almost exclusively on the choice between shared ownership and sole ownership (e.g., Gomes-Casseres, 1990). Only Blodgett (1991) has examined the effects of government restrictions on the ownership distribution of JVs from a bargaining power perspective.

9. Other JV studies have contrasted TCE and RO theory in different ways. Folta (1998) argued that RO theory and TCE contradict rather than complement each other. Specifically, he argued that TCE emphasizes the use of commitment to reduce uncertainty, while RO theory emphasizes flexibility to deal with uncertainty. Furthermore, he proposed that there is a trade-off between these two stances, and that

this trade-off is more prominent under conditions of high uncertainty. Conversely, Chi (2000) and Reuer and Tong (2005) argued that explicit call options in JVs are one of several contractual safeguards that can be used to reduce transaction costs – thus suggesting that RO theory and TCE are overlapping. Clearly, these studies raise interesting questions for future research, the most critical of which we outlined above in the section dealing with JVs as (explicit) ROs. On balance, however, current empirical evidence in studies of initial JV equity stakes suggests that RO theory and TCE are complements.

10. *Current dividends* are a function of market size, first-mover advantages, and learning opportunities. The *residual resource value* is determined by the uniqueness, transferability to other markets, and durability of the underlying resources. The *exercise price* depends on whether there is an explicit contractual option, and the proprietariness of the option. The *value of the option* depends on the amount of exogenous uncertainty, the threat of preemption, and the presence of unique complementary resources (Miller & Folta, 2002).

11. We discuss learning in this section because the range of its manifestations and effects is better understood in connection with alliance evolution and (in)stability than solely in connection with terms at founding (initial distribution of equity). Conversely, the literature on agency theory has relatively little to say about alliance instability (other than as adjustment of terms, following a logic similar to transaction cost predictions), so we do not treat it separately in this section.

12. In accordance with the existing literature, we focus here on call options. However, a similar argument can be made for put options that give the holder the right to sell its share. The likelihood that a firm has an explicit put option should also be higher when it expects its bargaining power to deteriorate during the life of the JV.

13. Although Miller and Shapira (2004) provided the respondents in their experiment with objective information about the distribution of uncertainty, they suggested that biases in the assessments of probabilities might also be relevant to the valuation of options.

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HOW DO REAL OPTIONS MATTER? EMPIRICAL RESEARCH ON STRATEGIC INVESTMENTS AND FIRM PERFORMANCE

Jeffrey J. Reuer and Tony W. Tong

ABSTRACT

This paper categorizes and critiques the empirical research strategies that have been employed to test real options theory. Existing research has sought to detect valuable options in firms' strategic investments as well as to investigate the payoffs from these investments. Our review highlights some of the evidence that has accumulated in recent years for real options theory. We flag some of the most important challenges and tradeoffs associated with the use of different empirical research approaches for testing real options theory in strategic management. The paper concludes by offering a number of research priorities to advance the theory by probing its descriptive validity as well as by addressing its normative aspirations to bridge corporate finance and strategy.

INTRODUCTION

During the last decade or so, considerable theoretical progress has been made in the strategy and management literatures on real options. This work

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initially conceptualized a wide range of organizational phenomena as options, mapping diverse investments and activities such as R&D and technology strategy (e.g., Mitchell & Hamilton, 1988; Kogut & Kulatilaka, 1994a; McGrath, 1997), foreign direct investment (FDI) (Kogut, 1989; Kogut & Kulatilaka, 1994b), venture capital and entrepreneurship (e.g., Hurry, Miller, & Bowman, 1992; McGrath, 1999), etc., into the real options taxonomy of growth, deferral, switching, abandonment, as well as other options (e.g., Trigeorgis, 1996).

Some of the research that followed has relied upon the formalism of economics, finance, and operations research to determine the workings of real options and option value drivers (e.g., Huchzermeier & Cohen, 1996; Chi, 2000; Huchzermeier & Loch, 2001). Other research has taken a more intuitive tack and has placed fewer restrictions on the criteria for options to exist, the potential application domains, and the theory's boundaries. Recent work has also begun to use real options analysis in conjunction with other theories such as game theory (Smit & Trigeorgis, 2004), organizational learning (McGrath & Nerkar, 2004), and capability-based perspectives (Kogut & Kulatilaka, 2001) to examine questions surrounding the theory of the firm and competitive advantage. Recent research has also identified and debated some of the potential pitfalls of importing options concepts from financial economics to organizations, which are occupied by boundedly rational managers bringing their own cognitive biases and other limitations to firms' resource allocation processes (e.g., Bowman & Moskowitz, 2001; Adner & Levinthal, 2004; Kogut & Kulatilaka, 2004; Miller & Shapira, 2004).

Despite this progress in framing and conceptual application, the developments on the empirical side have not kept pace. Throughout our paper we note some of the challenges and tradeoffs associated with testing real options theory in different strategy domains, and this discussion helps explain in part why the gap between theory and empirical evidence persists. Clearly, some of the challenges also find their roots in outstanding theoretical challenges or in what scholars expect of real options theory in strategy. For instance, debates continue on the assumptions that must be met, or not, for real options to be valued, as well as on appropriate modeling methods (Lander & Pinches, 1998; Bowman & Moskowitz, 2001; Copeland & Antikarov, 2005). Such issues might be critical for certain applications, yet take on lesser significance in other areas. Other challenges are as mundane as data collection obstacles that researchers face in obtaining detailed information to measure the theory's core constructs at the level of individual option purchase or exercise decisions, which is not an unfamiliar problem for strategy researchers.

Yet convincing tests are needed for at least two important reasons. First, empirical studies are needed to investigate the descriptive validity of real options for various strategic phenomena in order to advance the theory. Second, real options theory purports to be a normative theory that can bridge corporate finance and strategy by injecting strategic reality (e.g., follow-on opportunities, managerial discretion in the face of uncertainty, etc.) into traditional capital budgeting models and by bringing the discipline of financial markets to bear in strategic analyses (Myers, 1984a; Amram & Kulatilaka, 1999). This aspiration, coupled with the limited or modest usage of the concepts and tools of real options in actual companies (Busby & Pitts, 1997; Triantis, 2005), suggests that empirical research might also be critical for real options analysis to gain traction and enhance practice in the coming years.

In this paper, we will classify and reflect on several empirical approaches that scholars have employed to test real options theory in strategy research. Our focus will be on reviewing and critiquing the major categories of empirical investigations that have recently been conducted in strategic management, as opposed to offering an exhaustive review of all of the accumulated evidence on real options in strategy or other literatures. We begin with a discussion of the research that has examined the timing or structuring of firm's investments using real options theory. We then turn to a complementary stream that examines the performance implications of firms' options investments. We devote more attention to this second body of research because more background material from related fields (e.g., finance, accounting) is needed to describe key constructs, and because this is where our own research on real options has been focused. We also elaborate on some of the tradeoffs presented by the different empirical strategies, and we make note of several research priorities for advancing real options theory in strategic management research.

EMPIRICAL RESEARCH ON REAL OPTIONS IN STRATEGY

Fig. 1 presents a categorization of some of the major strands of empirical research on real options within strategy and management. The diagram also offers a few examples of research within each of the categories. As the figure illustrates, existing empirical research has largely proceeded along two broad paths. First, several studies have followed what might be termed a

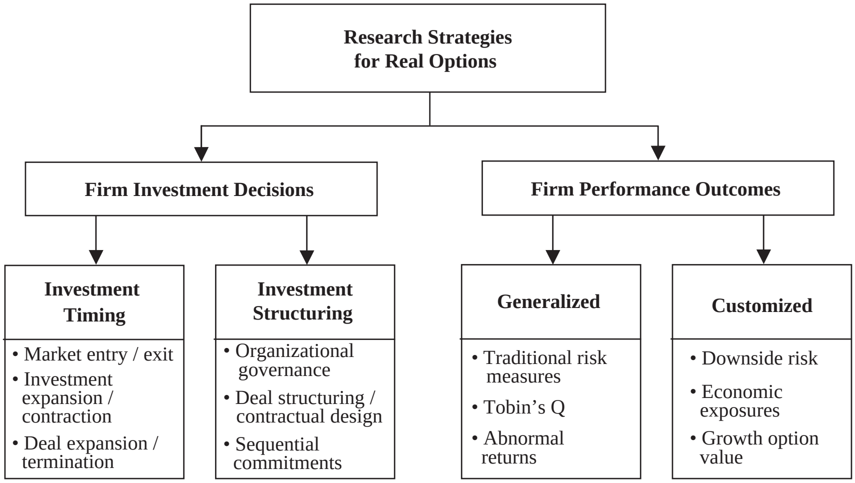

Fig. 1. Empirical Research on Real Options.

"decision-theoretic" approach by investigating how real options shape firms' investment strategy and behavior. By this, we mean that the tests focus on the drivers of firms' investment decisions, whether at the individual investment or portfolio level. One branch of this stream of research examines the *likelihood and timing* of firms' investments. This research focuses on the antecedents that determine whether or when firms will make certain investments (e.g., market entry, M&A, etc.). A second branch of this stream examines the *structuring* of firms' investments. This work gives attention to the variables that lead firms to structure investments in one way or another (e.g., ally versus acquire, make versus buy, etc.), conditional on an investment-taking place.

Second, a number of studies have investigated the *performance outcomes* of real options by attending to the consequences of firms' investments in options, as opposed to their causes, as noted above. One branch of this stream of research has relied upon *generalized* performance measures that are also often used in other areas in strategy, regardless of the theoretical or empirical domains (e.g., traditional risk measures, Tobin's *Q*, abnormal returns, etc.). A second branch of this stream has employed several *customized* performance measures that are specifically geared toward testing particular payoff structures that real option theory emphasizes. Each will be discussed in turn.

Firm Investment Decisions

Timing of Investments

Research on the likelihood and timing of firms' investments begins with the observation that a firm's decision to invest in a particular market, technology, etc., at a point in time will reflect the presence or absence of different types of options. As a simple illustration, suppose a firm is seeking to diversify into an emerging product market, and this opportunity requires investments in specialized assets that would be difficult to redeploy to other uses within the firm or sell on a resale market. The combination of uncertainty and irreversibility suggests that the firm will attach value to waiting and seeing how the product market uncertainty gets resolved (Dixit & Pindyck, 1994). Thus, if this deferral option (i.e., D) is sufficiently valuable, the firm will postpone the investment, even if it has a positive net present value at the time of evaluation (i.e., $NPV–D<0$, despite the fact that $NPV>0$). In other cases, investments in new markets will create valuable follow-on options, for instance, to expand facilities, enter new geographic areas, and so on. In such situations, even if the traditional NPV is negative, a firm may rationally seek to invest if these growth, or call, options (i.e., C) are sufficiently valuable. In other words, investment is value-enhancing for shareholders if the "package value" of $NPV+C>0$, despite the fact that $NPV<0$ and the classic textbook criterion for investment fails. It follows that time-varying changes in the value of these deferral and growth options can shape the likelihood or timing of firms' investments.

Explicitly valuing deferral and growth options can be difficult in individual investment projects for which detailed data are available. Option valuation therefore becomes all the more problematic in large-sample empirical analyses examining broad cross sections of firms. To examine growth options, for example, a stream of research has turned to the stock market for valuation information, yet this approach also presents challenges such as levels of analysis issues and the fact that stock prices also reflect the value of assets in place. Valuing deferral options is equally difficult, and prior research has noted that managers implicitly value such options since they use hurdle rates for investments that are greater than the firms' cost of capital (Dixit & Pindyck, 1994). However, more direct evidence, even from a smaller number of cases for which such valuation obstacles can be overcome, would be valuable in helping researchers better understand how these options figure into firms' decision-making concerning whether or when to make certain investments.

What strategy studies have done in light of difficulties such as these is to model statistically the underlying factors that are known to be associated with option value. The familiar Black-Scholes model, for instance, identifies five determinants of the value of a simple European call, which can apply to growth options under certain circumstances. These five option value drivers are the value of the underlying asset, the exercise price, the level of uncertainty, the risk-free rate of return, and the time to maturity. It is important to note, however, that real options often depart from such simple financial calls in many important respects: the exercise price can be correlated with the value of the underlying asset rather than known with certainty and fixed, especially if exercise prices are negotiated ex post rather than contractually specified ex ante; there may be carrying costs associated with holding the option open; and while time to maturity is a simple matter in the case of financial calls, it can be difficult to ascertain in strategy contexts. To date, empirical research in strategy has paid particular attention to uncertainty, which is not only a core variable in option valuation models, but it is also a variable that obviously has a natural affinity with other streams of research and theories in strategic management.

However, even estimating the impact of uncertainty on the likelihood or timing of investment is not as straightforward as it may appear. This complexity is due to the fact that, for a given investment situation, multiple options can be present that encourage or discourage investment, and increases in uncertainty can enhance the value of these options that may interact with one another (Trigeorgis, 1996). The complications this poses for researchers' falsification efforts can be illustrated with a simple example. Consider a statistical model that demonstrates a positive relationship between uncertainty and market entry. This effect would be consistent with the presence of growth options in a particular investment context, as noted above. However, if the effect is negative instead, this relationship can be consistent with the presence of valuable deferral options, which work against entry. Even in the case of an insignificant relationship between uncertainty and entry, the presence of options cannot be rejected since there might be deferral and growth options that are offsetting one another, taken with the traditional NPV rule. As such, positive, negative, or insignificant relationships between uncertainty and entry can be consistent with the presence of one or more types of options. In view of this, what is needed is a set of additional variables to tease apart these options and understand the policy regions under which one option is more or less valuable than the other and therefore increases or decreases the likelihood of entry (Kulatilaka & Perotti, 1998; Lin & Kulatilaka, 2007).

This issue of multiple options lurking behind strategic investments is a general problem that crops up in many applications of real options theory, whether or not it is acknowledged or can be dealt with empirically. Folta and O'Brien (2004) have tackled this issue in the context of product market entry in two novel ways. First, they argued that different option logics dominate at various levels of uncertainty. For instance, they suggested that the maximum value of the deferral option is bounded by the total sunk cost associated with entry into an industry, so the growth option's value will likely dominate at the highest levels of uncertainty. Their empirical results confirmed a non-monotonic relationship between uncertainty and entry: uncertainty reduces the likelihood of entry at low levels of uncertainty and its effect turns positive at high levels of uncertainty, but not until the 94th percentile is reached. Second, they also examined a number of factors that are apt to moderate the relationship between uncertainty and market entry, and these contingencies help disentangle the options. For example, they incorporated several measures of irreversibility and found that uncertainty and irreversibility interact to reduce the likelihood of entry as the theory predicts.

Although this study has examined the role of uncertainty in elevating the value of growth options a firm *purchases* from initial market entry, earlier research on the timing of the firm's investment decisions focused on the firm's *exercise* of growth options it already possesses. Kogut (1991), for example, developed the argument that joint ventures are investment vehicles that confer growth options, and he argued and showed that firms expand through the acquisition of additional equity when the venture experiences a positive demand shock (see also Folta & Miller, 2002). For instance, if V is the time-varying value of the venture, α is the firm's equity stake, and P is the price at which the other partner's stake might be purchased, then αV is the value of the focal firm's stake, and $(1-\alpha)V$ is the value of the part of the joint venture it does not own. The firm therefore can gain $(1-\alpha)V - P$ if it buys out the joint venture, and it will not do so unless $(1-\alpha)V > P$, so the terminal value of the call option is represented by $\text{Max}[(1-\alpha)V - P, 0]$. This formulation and test raises several questions, such as how P is negotiated (e.g., ex ante or ex post), what types of costs firms need to bear to keep this option alive, whether the firm is therefore able to limit its downside losses by investing in joint ventures, and which party is the buyer versus seller at the JV acquisition stage (e.g., Chi & McGuire, 1996; Chi, 2000; Cuypers & Martin, 2007). There is also a question about what the firm's intentions were at the time of the initial investment, since real options theory connects firms' rights and payoffs in a future period to investments made and claims secured in an earlier period.

Just as there are challenges associated with efforts to falsify real options theory in analyses of how uncertainty affects initial market entry, it can also be difficult in general to distinguish real options from other theoretical explanations in analyses that would just focus on option exercise decisions. Neoclassical investment theory, for instance, would also suggest that firms expand when their investment opportunities and expected returns improve. However, Kogut (1991) demonstrated an important asymmetry that is consistent with the presence of growth options embedded in joint ventures: firms do *not* dissolve their joint ventures in the case of *negative* market signals. Nevertheless, being able to conclude definitively that persistence in the face of negative market signals is tantamount to holding options open requires one to exclude alternative explanations such as decision biases, agency costs, and/or other organizational costs (e.g., Adner & Levinthal, 2004; Adner, 2007; Coff & Laverty, 2007).

Structuring of Investments
In the previous example, the terminal value of the growth option in the joint venture is negatively related to the firm's initial ownership stake, α, holding everything else constant. Firms that put less equity into their corporate investments are potentially able to reduce their downside losses and are in a position to expand and capture more value at the termination stage. When $\alpha = 1$ at the outset (e.g., as in an acquisition), the firm bears the investment risk itself and does not have ownership structure as a lever to adjust its commitments to the investment over time. Thus, one of the implications of Kogut's (1991) model is that joint ventures are preferable to acquisitions when the firm seeks to obtain growth options through external corporate development and maintain flexibility. Folta (1998) tested this core proposition of real options theory and found that equity alliances – both joint ventures and minority equity investments – are preferred to acquisitions, the greater the exogenous technological uncertainty, which is defined as the standard deviation of stock returns for companies in the focal firm's technological subfield.

Other research has used real options theory to examine not only the structuring of individual deals or investments in isolation, but also the firm's overall portfolio of options or how this option portfolio affects individual investments. Leiblein and Miller (2003), for example, investigated the relationship between semiconductor firms' product-market diversity and their decisions to vertically integrate production, using real options to argue that product-market diversification offers firms switching options, provided that they own their production. These options enable firms to manage capacity across product applications by converting the technology for other applications, for example if demand falls short for a particular product. These options also enable companies to shift the use of a process technology to less demanding product applications over time as the process technology obsolesces.

As a second illustration, Hurry et al. (1992) compared the institutional arrangements in the Japanese and U.S. venture capital industries and argued that VCs in Japan are more likely to follow an 'options strategy' of seeking new technology, whereas VC companies in the U.S. are more likely to use a 'project strategy' of direct venture gains. They compared 20 VC firms in Japan with an equal number in the U.S. and reported that the portfolios of Japanese VCs are much broader and consisted of smaller individual investments as well as a higher proportion of loss-making ventures. This work illustrates the testing of real option variables that are broader in nature (e.g., number and size of investments) rather than those directly featured in formal valuation models (e.g., uncertainty, irreversibility, etc.). In general, as noted above, tests of real options theory are prone to competing explanations (e.g., economies of scope, agency costs, or decision biases, etc.), and this risk would generally seem to increase as tests become more indirect and real options theory is used in broader, more metaphorical terms.

More recent work has sought to combine some of the best approaches noted above by bridging levels of analyses, modeling the variables core to option theory, and/or examining how options in a firm's portfolio positively or negatively shape the value of other options held by the firm. McGrath and Nerkar (2004), for instance, concluded that pharmaceutical firms' failure to take out additional options (i.e., patents) in technological areas where they previously acquired options diminishes the value of previous options since new discoveries with growth prospects become less likely. Vassolo, Anand, and Folta (2004) studied how the technical proximity among a firm's R&D alliances leads to a sub-additive option portfolio due to overlaps among these investments (i.e., the value of the portfolio of options is less than if they were each independently owned). In the case of McGrath and Nerkar (2004), failing to take out options in an area where the firm has R&D experience reduces the growth option value (GOV) of previous investments; in the case of Vassolo et al. (2004), the ability to switch to the option with the highest value erodes the value of other options. As noted earlier, the presence of multiple types of options, in this case interrelated growth and compound switching options (i.e., the option to switch across options), makes empirical analyses of option portfolios interesting yet more challenging. Such analyses also need to attend to the simultaneity versus sequentiality of such investments, as well as the separation of portfolio, learning, and other effects that can arise from firms' accumulated partnerships or other investments over time (Anand, Oriani, & Vassolo, 2007).

Firm Performance Outcomes

The above research has offered evidence on the descriptive validity of real options theory in different strategy settings (see also McGrath, Ferrier, & Mendelow, 2004), but a second core question that arises is whether firms actually derive the benefits that real options theory holds out for them. Even if firms are purchasing and exercising options as the theory predicts, it is also true that obtaining, holding onto versus abandoning, and exercising options all have costs associated with them. These costs are rarely noted, but they can have an important impact on the value a firm ultimately captures from real options (see Fig. 2).

First, options can be viewed as being exchanged in factor markets (Myers, 1977), so firms need to pay a price to get them, whether in the form of an upfront outlay or in other terms related to a transaction. For example, a firm may obtain a growth option through an acquisition, but if the option is purchased through bidding and the target obtains a premium that reflects its attractive growth prospects, the firm might not capture much, if any, value from the growth option. Buyers and sellers of options can also suffer from adverse selection that arises when information is unevenly distributed across exchange partners. Such information asymmetries can lead to buyers facing a risk of overpayment as well as sellers experiencing discounted offer prices for the assets they are selling (Akerlof, 1970).

Second, it is important to note that for real options, unlike financial options, the costs of keeping them open are far from trivial. For example, some of the investment vehicles to access options, such as joint ventures, have been shown in previous research to be extremely difficult to manage.

Investment Stage:	Purchasing Options	Managing Options (e.g., hold vs. abandon)	Exercising Options
Illustrative Theoretical Concerns:	• Factor market competition • Bargaining under asymmetric information	• Decision biases • Agency costs	• *Ex ante* contracting • *Ex post* negotiation

Fig. 2. Capturing Value from Real Options.

Much of the skepticism on the value of real options analysis centers around the organizational inefficiencies associated with decisions to keep options alive (e.g., Adner & Levinthal, 2004; Adner, 2007), and at the extreme these costs are seen as overwhelming the benefits that options potentially can bring to firms. However, if a firm manages the purchase and exercise decisions well, it can still stand to capture option value despite the costs associated with holding onto or disposing options (e.g., Coff & Laverty, 2007).

Third, the final stage concerning option exercise is also a setting in which value can be appropriated by others rather than the option holder. For example, in the case of equity collaborations, strike prices are routinely subject to negotiation ex post rather than specified ex ante, which can limit the value a buyer can capture. However, even in the case of ex post negotiation of partner buyout prices, a buyer may stand to gain from the trading of options if the partners anticipate an ex post divergence in their valuations of the venture (Chi & McGuire, 1996). Such ex post divergence in valuations often arises due to heterogeneity in partners' complementary assets and synergies with the venture.

While the above discussion focuses on the challenges firms face in appropriating value from real options within distinct investment stages, the challenges can also interact across different stages and can be connected to one another. For example, the problems associated with the appropriate exercise of options might be less severe for options obtained externally, but such options are more prone to factor market competition at the option purchase stage. By contrast, firms might be more likely to avoid such competition for options developed internally, yet they might face greater organizational challenges in managing and exercising such options, which can erode the option value created at an earlier stage.

In the following, we review and critique the empirical research that has examined the performance implications of real options, and this research has also proceeded along two paths. First, several studies have examined the implications of options for a set of traditional performance measures that are widely used in other theoretical and empirical domains in strategy. Second, more recent studies have developed and used measures of firm outcomes that are more specifically customized to real options.

Generalized Performance Measures

A number of analyses have explored whether certain investments have a positive impact on firm performance, and such effects have been interpreted using the real options lens. Three examples typify the general approach. Allen and Pantzalis (1996) examined how the breadth and depth of firms'

FDI affect their valuations, as measured by Tobin's *Q*. More recently, Kumar (2005) investigated the abnormal returns to firms acquiring and divesting joint ventures, which can be viewed as the exercise or abandonment of growth options. Ho, Tjahjapranata, and Yap (2006) examined the effects of firm's R&D investments on their growth opportunities, as proxied by Tobin's *Q*.

One of the primary difficulties that arises with the use of generalized performance measures such as these dependent variables is that they reflect benefits and costs that are also derived from assets other than options. For instance, in the case of abnormal returns, the value the market attaches to firms' investment decisions not only reflects incremental cash flows from future discretionary investments a firm obtains, but also cash flows from assets in their current uses (both net of the purchase price), making it difficult to understand whether enhanced firm value is due to the traditional NPV of an investment or the follow-on growth opportunities that the investment presents with an option nature. This observation suggests that studies of abnormal returns or other generalized performance measures will need to use statistical analyses to separate out these effects, e.g., through appropriate specification of controls and contingencies on the right-hand side, such as interactions with uncertainty (Chi & Levitas, 2007).

Tobin's *Q* deserves separate comment since it is a measure that has often been used to measure firms' growth opportunities. It is important to note, however, that using this measure also has some limitations that may necessitate the steps in model specification noted above. Theoretically, Abel, Dixit, Eberly, and Pindyck (1996) suggested that Tobin's *Q* reflects both excess returns on existing capital and the value of options to invest, or growth options. Furthermore, Berk, Green, and Naik (1999) analysis showed that firms with different levels of growth opportunities can have identical market-to-book values, or *Q*, indicating that Tobin's *Q* may be an unsatisfactory proxy for growth options. Moreover, in prior empirical analyses in economics and finance, Tobin's *Q* has been used to capture a number of diverse theoretical constructs, such as monopoly power (e.g., Lindenberg & Ross, 1981), management quality (e.g., Lang, Stulz, & Walkling, 1989), and shareholder value and intangible resources (e.g., Lev, 2001), so the use of Tobin's *Q* as a measure of growth options can have limitations, and potential confounds such as these need to be acknowledged and addressed. In a subsection below, we will discuss the relationship between Tobin's *Q* and other measures of firms' growth options.

Along related lines, several studies have used traditional measures of organizational risk and have drawn conclusions on the benefits firms can derive from real options. As one example, several studies have reported that multinational investment tends to stabilize firms' income streams (see Caves, 1996 for a review). However, drawing conclusions on the options and operational flexibility of multinational firms is complicated by the fact that while options enable firms to truncate their downside losses, they also allow firms the twin benefit of access to upside opportunities (Kogut & Kulatilaka, 1994b). These upside opportunities may increase, rather than decrease, standard measures of risk that are built upon the dispersion of a company's returns around a mean value.

Due to these and other challenges associated with using generalized performance measures to test real options theory, several more customized measures have been used in the literature. As will be discussed, these measures have several advantages that enable researchers to test certain aspects of real options theory. Using these approaches allows researchers to employ downside conceptualizations of risk, to study firms' economic exposures to particular sources of uncertainty, and to examine the value of firms' growth options, among others. These empirical strategies also present some unique challenges compared to the research previously discussed on the timing and structuring of firms' investments.

Customized Performance Measures

For an option to exist, it must give the firm a right but not an obligation to take some future specified action, enabling the firm to reduce its downside risk and access upside opportunities. The first part of the sentence simply reflects the point that the firm obtains a decision right, or discretion, from the option. When such rights are absent, or when certain future actions become obligations (e.g., due to legal or psychological contracts), the power of the option logic breaks down. Moreover, when this decision right combines with uncertainty, it carries implications for the structure of the firm's payoffs, as reflected in the latter part of the sentence. Specifically, like financial options, real options have a non-linear payoff function that allows the call (put) holder to mitigate downside losses (e.g., when product-market demand or some other source of uncertainty is below (above) some threshold value), and exploit the uncertainty to reap rewards (e.g., when demand is above (below) some threshold value). The three customized measures of firm outcomes discussed below are geared to exploit particular payoff structures predicted by real options theory.

Downside Risk. Measures of downside risk are attractive in testing the ability of certain investments with embedded options to reduce firms' downside losses. Miller and Reuer (1996) draw upon research in finance, behavioral decision theory, and management to motivate risk measures based upon a downside conceptualization of risk rather than more traditional, variability formulations. They specify three categories of downside risk, two of which have been utilized to test real options in different organizational settings. They first discussed root lower partial moment measures, which can be represented for discrete data using the following formula:

$$\mathrm{RLPM}_{\alpha}(\tau;j) = \left[\left(\frac{1}{N}\right)\sum_{r_j<\tau}^{\tau}(\tau - r_j)^{\alpha}\right]^{1/\alpha}, \quad \alpha>0 \qquad (1)$$

where N is the number of time periods investigated, and α reflects the importance of performance shortfalls below some target value, τ. The target value might be set equal to zero for breakeven performance, equal to the performance of direct rivals with which firm j compares itself, or equal to firm j's own lagged performance, though in practice risk measures using these alternative targets are highly correlated. When $\alpha = 2$, this measure is a "target semideviation" (e.g., Harlow, 1991), which is analogous to a standard deviation, except that the target value replaces the mean, and only the performance shortfalls (i.e., $r_j<\tau$) figure into the calculation. This restriction on the summation and the multiplication by $(1/N)$ indicate that periods in which firm performance is at or above the target implicitly receive a value of zero. In a factor analysis of alternative risk measures, Miller and Reuer (1996) found that Eq. (1), when specified using $r_j = \mathrm{ROA}$ of firm j, $\tau =$ lagged industry average ROA, and $\alpha = 2$, provides a downside risk measure that proxies the firm's income stream risk. When ROE data are used instead, the measure is related to the firm's bankruptcy risk, as indicated by its negative correlation with Altman's Z ($p<0.001$), an inverse bankruptcy-risk discriminant score that has been used in strategy studies as an inverse proxy for organizational risk (e.g., D'Aveni & Illinitch, 1992).

Second, they considered a downside measure of risk derived from the Capital Asset Pricing Model (CAPM). A summary of the technical details of the modified CAPM appears in their paper, but the estimation of the second-order mean lower partial moment (i.e., β_j) can be done using the following simple regression model for each company j:

$$r_{\mathrm{jt}} = \beta_{0j} + \beta_j r_{\mathrm{mt}} + \varepsilon_{\mathrm{jt}}, \quad \text{for all } t \text{ such that } r_{\mathrm{mt}}<i_{\mathrm{t}} \qquad (2)$$

Unlike in the case of the standard market model, this specification is estimated only for time periods in which the market return, r_{mt}, falls short of some target value, such as a risk-free rate of return (i.e., $r_{\mathrm{mt}} < i_{\mathrm{t}}$). Their factor analysis results indicated that this measure of downside risk (i.e., β_j) provides a measure of the firm's systematic risk that is distinct from the other operational measures of downside risk and has a correlation with the standard beta of 0.49.

Reuer and Leiblein (2000) used these measures of downside risk to investigate whether firms are able to use two classes of real options to reduce their downside losses. First, they examined whether the growth options available from joint ventures reduced firms' downside risk. They found, contrary to real options predictions, that both domestic and international joint ventures increase firms' income stream risk and bankruptcy risk, and these two types of joint ventures had no impact on their systematic risk (i.e., downside beta). Second, they investigated whether the switching options provided by the dispersion of FDI reduces firms' downside risk. Kogut and Kulatilaka (1994b) theorized that firms straddling country borders are able to shift production or other value chain activities in response to changes in exchange rate movements or other uncertainties, such that the firm will enjoy the twin benefits of an increase in value and a reduction of downside risk (also see Huchzermeier & Cohen, 1996). For none of the three dimensions of downside risk did the dispersion of FDI have the predicted negative effects in the empirical study, however.

In another analysis of the heterogeneity in firms' option portfolios in multinational investment, Tong and Reuer (2007) employed models to control for unobserved firm resources or other characteristics that might have an impact on the relationship between FDI and downside risk. Their results indicate that downside risk initially falls as firms enter more foreign countries, but the complexity that accompanies extensive multinational operations leads to higher downside risk levels as the firm's FDI becomes even more dispersed. They also found that downside risk levels are increasing in the average cultural differences between the firm's home base and its foreign subsidiaries in its portfolio, and this finding is consistent with the idea that organizational complexity and coordination costs can limit the firm's ability to implement and benefit from such switching options.

Like the other approaches already discussed, this empirical strategy is also subject to several challenges and limitations. As we observed before, the separation of experience and portfolio effects; the replenishment, expiration, or exercise of options in a firm's portfolio; and the presence of multiple types of options (e.g., growth, switching, abandonment, etc.) make empirical analyses of option portfolios interesting and challenging. Moreover, as will be discussed below, analyses of downside risk only address one-half of the twin benefits that real options offer, so empirical investigations need to complement this approach by assessing how real options enhance firms' access to upside opportunities.

Economic Exposures. The downside beta measure just discussed can be viewed as the firm's "exposure" to the overall stock market when the market is performing worse than some target value, but many other types of uncertainties will matter for firms purchasing or managing various types of options, and these uncertainties can be exploited in empirical research in strategy.

One model in international finance augments the standard market model with a single foreign exchange rate, or a trade-weighted index of currencies (e.g., Jorion, 1990), to examine how exchange rate risk is priced in financial markets. Miller and Reuer (1998b) first conducted a factor analysis of exchange rates for the U.S.'s fifteen major trading partners and selected the currencies for the largest trading partners – the Japanese yen, the Canadian dollar, and the Mexican peso – for each of the three exchange rate factors that resulted. The resulting three-currency model was used to test economic exposures for a large sample of U.S. manufacturing firms:

$$R_{jt} = \beta_{0j} + \beta_{1j}R_{mt} + \beta_{2j}R_{rt} + \beta_{3j}R_{¥t} + \beta_{4j}R_{C\$t} + \beta_{5j}R_{Pt} + \varepsilon_{jt} \qquad (3)$$

where R_{jt} is the real stock return for firm j in month t; R_{mt} is the real, value-weighted market portfolio return in month t; R_{rt} is the percentage change in the real U.S. Treasury bill rate; and $R_{¥t}$, $R_{C\$t}$, and R_{Pt} are the percentage changes in the real dollar values of the Japanese yen, Canadian dollar, and Mexican peso, respectively. Like the standard market model, this specification is estimated for each firm individually. Exposure to exchange rate movements is indicated by a significant F statistic (i.e., F_j) for the null hypothesis H_0: $\beta_{3j} = \beta_{4j} = \beta_{5j} = 0$. For roughly 14% of firms, this null hypothesis can be rejected, and it can be concluded that these firms are exposed to foreign exchange rate movements.

In order to understand the determinants of firms' economic exposures, this firm-specific test statistic can be used in a second-stage model in which independent variables for real options and other factors appear. As alluded to above, the view that multinational operations confer switching options to firms involved in FDI (e.g., Kogut & Kulatilaka, 1994b; Huchzermeier & Cohen, 1996) suggests that firms with greater FDI should have lower economic exposure to foreign exchange rate movements, and Miller and Reuer's (1998b) findings are consistent with this prediction.

A subsequent study investigated the assumption in prior research that firms are exposed symmetrically to environmental uncertainties (Miller &

Reuer, 1998a). In the example just discussed, this assumption implies that the financial performance impact of an appreciation of the Japanese yen is offset by a depreciation of the Japanese yen of the same magnitude in absolute value terms. However, if a firm has options on assets whose values are tied to the value of the yen, its exposure to appreciations and depreciations in the Japanese yen are apt to be asymmetric.

Two situations of asymmetric exposures are consistent with the presence of real options. First, holding a call option on an asset that appreciates with the real value of the yen would be consistent with a positive exposure coefficient when the yen appreciates (i.e., $\beta_{3j}>0$) and no exposure when the yen depreciates (i.e., $\beta_{3j}=0$). In this sense, the firm is able to capitalize upon "upside opportunities" presented by appreciation in the yen. Second, holding a put option on an asset tied to the real value of the yen would be consistent with a negative exposure parameter when the yen depreciates (i.e., $\beta_{3j}<0$) and no exposure when the yen appreciates (i.e., $\beta_{3j}=0$). As such, there are nine possible combinations of exposure parameters (i.e., $\beta_{3j}>0$, $\beta_{3j}=0$, and $\beta_{3j}<0$, for yen appreciation and yen depreciation), and two of these combinations are consistent with options being attached to assets whose value is tied to the real value of the yen.

The combination consistent with holding a call option is also accommodated by a phenomenon called "pricing to market," which can arise due to two scenarios. One of these scenarios can yield exposure coefficients that are consistent with those arising from holding call options. Specifically, when the yen appreciates (dollar depreciates), U.S. exporters may choose higher home-currency markups if they face capacity constraints or quotas in distributing to foreign markets, and they do not choose equivalent markdowns during yen depreciation.

Miller and Reuer (1998a) found that, of the U.S. manufacturing firms that are exposed to foreign exchange rates, their exposures are indeed asymmetric. For the three-currency macroeconomic model appearing in Eq. (3), roughly 14% of the firms are exposed to appreciations or depreciations in the Mexican peso ($\alpha = 0.05$), and these figures are 12.5% and 5.4% for the Japanese yen and Canadian dollar, respectively. Only three firms (i.e., 1%) are symmetrically exposed to the Japanese yen, and no firms are symmetrically exposed to either the Canadian dollar or Mexican peso. Although the evidence indicates that some of the firms are exposed in a manner consistent with real options theory, the study did not examine particular investments or activities by firms that provide options and might explain these exposure profiles. Their findings indicate only weak evidence consistent with firms actively managing foreign exchange exposures in ways that enhance shareholder returns consistent with option theory (i.e., 5.0% for the Canadian dollar, 5.9% for the Japanese yen, and 5.0% for the Mexican peso), and in one of the two "option scenarios," the pricing-to-market phenomenon might account for some firms' asymmetric exposures.

Growth Option Value. The above analyses have investigated how various options can limit firms' downside losses or alter their exposures to particular environmental uncertainties, but they do not directly value the portfolio of options a firm possesses. A third stream of research has attempted to do this in a way that is more amenable to large-sample analysis than option pricing models for options in individual investment projects. This empirical strategy determines how important growth options are to firms' overall values and examines how investments that are thought to confer growth options explain the heterogeneity in the values firms actually derive from growth options.

This research has joined foundational research in finance on corporate valuation (e.g., Miller & Modigliani, 1961) with more recent research on value-based management to operationalize key inputs (e.g., Stewart, 1991; Young & O'Byrne, 2001). Some background material on these concepts is useful to understand and compare the measures that empirical studies might use.

The traditional theory of corporate valuation posits that a firm's value, V, can be broken into two parts: the present value of assets in place (i.e., V_A) and the present value of future growth opportunities (i.e., V_G):

$$V = V_A + V_G \tag{4}$$

These future growth opportunities can be viewed as call options on real assets in the sense that their ultimate value depends on firms' discretionary investments in the future (Myers, 1977). Assets in place, by contrast, are assets whose value does not depend on such investments.

Kester (1984) measured the value of growth options as the difference between a firm's market value and the capitalized value of its current earnings stream, discounted at a fixed rate for the full sample of firms (e.g., 15, 20, or 25%):

$$V_G = V - \frac{\text{Current earnings}}{\text{Discount rate}} \tag{5}$$

He found that, for many firms in his sample, valuable growth options constitute at least half their market value.

This methodology can be enhanced in two ways. First, more accurate measures of firm's GOVs might be obtained by using firm-specific discount rates to capitalize earnings. Second, accounting profits can be adjusted in order to provide for better proxies of economic profits. Below we provide an explanation of a measure using the Stern Stewart dataset that provides these two refinements, and a more detailed discussion of the techniques developed by Stern Stewart can be found elsewhere (e.g., Stewart, 1991). We then compare this measure with other measures of growth options such as Kester's, as well as with Tobin's Q (see Tong & Reuer, 2006).

To begin with, the total value of the firm (V) can be represented as the sum of two components:

$$V = \text{CI} + \text{MVA} \tag{6}$$

In other words, market value added (MVA) is simply the difference between the value of the firm (V) and the total capital that creditors and shareholders have entrusted to the company in the form of loans, retained earnings, paid-in capital, etc., which is labeled capital invested (CI). MVA, therefore, can be seen as the aggregate net value of all the firm's investments at the time of the calculation.

MVA can also be defined as the present value of the firm's economic value added (EVA) over time. EVA is trademarked and publicized by Stern Stewart, and it is a version of residual income, an economic concept tracing back to least Marshall's (1890) writings. Traditional accounting profit measures such as net income only consider the capital charges arising from debt capital, and they therefore ignore the opportunity cost of equity capital. Residual income therefore moves accounting profits closer to economic profits by subtracting both types of costs by applying the firm's weighted average cost of capital to the CI, as follows:

$$\text{RI} = \text{NOPAT} - [\text{CI} \times \text{WACC}] \tag{7}$$

where RI is residual income, NOPAT the company's net operating profits after tax, and WACC its weighted average cost of capital.

EVA is a version of residual income in that Stern Stewart adjusts income statement and balance sheet items to correct for several accounting anomalies or distortions to arrive at NOPAT and CI (see Stewart, 1991). By making these adjustments, Stern Stewart arrives at its own estimate of residual income and a more accurate measure of organizational performance that is centered on wealth creation for shareholders (Young & O'Byrne, 2001).

In order to arrive at a proxy of GOV, EVA in any given year can be broken into two parts: one that is equivalent to the current year's EVA (assuming zero growth), and the other called EVA Growth, which is either above or below the current level based on the firm's investments in growth opportunities. Negative investments in growth opportunities arise when the firm is unable to sustain current performance, or has made value-destroying investments (e.g., Myers, 1984b). Replacing MVA in Eq. (6) by the two components of EVA, the firm's value can be rewritten as follows:

$$V = \text{CI} + \text{PV of Current EVA} + \text{PV of EVA Growth} \tag{8}$$

where the sum of CI and PV of Current EVA constitute the value of the firm's assets in place (i.e., V_A), and PV of EVA Growth is the value of the firms' growth options (i.e., V_G, the residual portion of the value of the firm due to growth options).

To calculate the firm's GOV, Eq. (8) can be solved for PV of EVA Growth, which is then scaled by the firm's value (V):

$$\text{GOV} = \left[\frac{V - \text{PV of Current EVA} - \text{CI}}{V}\right] \tag{9}$$

The PV of Current EVA is calculated by treating the firm's current EVA as a perpetuity discounted by the firm's WACC. All the other terms appearing on the right-hand side, as well as the estimate of the firm's WACC, are available from the Stern Stewart database.

Given that this method can trace its lineage back to Kester (1984), it is interesting to compare this measure of GOV with the one calculated by applying Kester's approach to Compustat's accounting data. The correlation between the two is 0.79 ($p < 0.001$) for the sample, suggesting that GOV measures that do not rely on Stern Stewart's value-based measures and accounting adjustments might suffice, when such data are not readily available. Kester's approach is also attractive for certain sampling frames, since the Stern Stewart dataset is limited to the 1,000 U.S. firms with the largest MVAs and the non-U.S. coverage is limited.

It is also useful to compare these measures of firms' GOVs to Tobin's Q, which has often been used as a proxy for firms' growth opportunities, in addition for diverse theoretical constructs such as monopoly power (e.g., Lindenberg & Ross, 1981), management quality (e.g., Lang et al., 1989), and shareholder value and intangible resources (e.g., Lev, 2001). The correlation between the value-based measure of GOV and Tobin's Q is only 0.22. The correlation between the accounting-based measure of GOV and Tobin's Q is even lower (i.e., $r = 0.10$). These findings are in accord with recent suggestions that Tobin's Q may not well proxy for firms' value of growth options (e.g., Abel et al., 1996; Berk, et al., 1999).

In a series of papers, Tong and Reuer examined the factors that are associated with firms' GOVs. They first considered the degree to which firms benefit from options that are shared among industry incumbents versus those that are proprietary, or firm-specific (Kester, 1984; Trigeorgis, 1996). Variance decomposition analyses indicate that firm effects account for roughly 29% in the variance of GOV (Tong & Reuer, 2006). They examined different subsamples of firms such as single- and multi-business firms, and found that firm effects always dominate industry effects: firm effects are between 1.5 and 2.5 times as important as stable and transitory industry effects combined. Thus, while shared options are important, it appears that it is the heterogeneity in firms' proprietary options and the differences in how firms manage them that matter the most in explaining the variance in the value that firms can actually capture from growth options. As a broader observation, empirical research has not frequently differentiated shared and proprietary options, nor has it provided direct evidence on the relative importance of the two, so future studies might explore additional implications of this important distinction as well as the sources of valuable options.

They then investigated different internal and external corporate investments by companies that contribute to firms' GOVs. Investments in research and development stand out as enhancing firms' GOVs (Reuer & Tong, 2007). Concerning external corporate development activities by firms, investments in equity alliances are positively associated with GOVs, though this effect is limited to minority joint ventures. Neither majority joint ventures nor minority acquisitions appear to enhance firms' GOVs. The findings illustrate the importance of certain contingencies (e.g., ownership structure) that shape the value of growth options and emphasize the need for empirical studies to consider the boundary conditions of real option predictions.

Another paper extended the focus into international joint ventures (Tong, Reuer, & Peng, 2007) and investigated the growth options that have often been attached to emerging economies in particular, due in part to the uncertainties presented by the underdevelopment of market-supporting institutions in these investment contexts and other sources of exogenous uncertainty (e.g., Hoskisson, Eden, Lau, & Wright, 2000; Peng, 2000). The paper found that international joint ventures in emerging economies generally do not enhance firms' GOVs, unless the venture is either in a product-market outside of the firm's core business or the firm takes on less than 50% ownership in it. These contingent effects of product-market focus and ownership structure are applied to international joint ventures in developed countries as well. Thus, combining these findings with those above on joint ventures' impact on downside risk, it appears that neither domestic nor international joint ventures reduce firms' risk levels, yet they do enhance firms' GOVs, at least under some well-defined conditions.

The main advantage of this line of research is that researchers can directly examine the value of firm's growth options, but this empirical strategy also comes with certain limitations. Like much of the research previously discussed, the core constructs are at the firm, or portfolio, level of analysis. For certain purposes, this approach is attractive and useful, but it potentially limits the amount of detail at the investment or project level that might be accommodated. This empirical strategy also is not designed to tease apart different types of options such as abandonment or deferral options. Finally, in the work above, which develops direct links between firms' various investments and option values, important organizational dimensions to the management of options are presumably working in the background, but they are black-boxed in statistical models.

FUTURE RESEARCH DIRECTIONS

Our review and critique have illustrated the rich diversity of emerging empirical studies on real options theory as well as some of the difficulties and tradeoffs associated with the various empirical strategies that are in use in strategic management research. Our review indicates that, for certain empirical research streams, the results are more mixed than for others. Moreover, when individual tests are probed carefully, there might seem to be few "smoking guns" for real options theory in the strategy literature. It is fair to say that considerable progress has been made in the last ten years or so, however. It is also evident that recent empirical research has offered stronger tests of the theory.

Recent tests have shown greater complexity and sophistication for several reasons. For instance, while most early research began by mapping features of investments to certain types of options, advancements have come by integrating insights from real options theory with other theories and perspectives (e.g., organizational learning, resource fungibility, transaction cost theory, competitive dynamics, etc.). In addition, empirical tests have become more complicated and sophisticated by attempting to disentangle various types of options that are attached to certain investments (e.g., growth and deferral options), by analyzing how the presence of certain types of options may interact with the other types of options in a firm's portfolio, and by using more customized measures of firm outcomes that are better geared toward the unique payoff structures theorized by real options.

As we consider the research challenges and opportunities that lie ahead, there are several important priorities that have come into light from our review and critique that we would like to underscore. First, we believe that one of the most neglected areas of empirical research on real options concerns implementation. This point has been made several times above, and we see the need to pay attention to organizational and managerial aspects of managing options as one of the most pressing research needs. For instance, unlike in the case of financial options, managers need to devote time and cost to search for potential, latent options inside and outside of the firm (e.g., Bowman & Hurry, 1993). The implications of organizational systems for real options and vice versa need to be considered, and attention needs to be devoted to metrics for evaluating managers. Given that one of the main objectives of real options research is to join capital budgeting processes with strategic analyses, detailed investigations into such processes are required, and strategy scholars are uniquely positioned to make such contributions. Studies in these directions could examine specific investments with embedded real options (e.g., R&D, equity collaborations, etc.) or could connect with real options analyses, which can be seen as a set of valuation tools and/or decision-making heuristics that can figure into organizational processes.

Our review has shown that there are two dominant streams of empirical research that primarily focus on the timing and structuring of investments, and the firm outcomes of such investments. We envision that the research streams will become increasingly linked, and it is our hope that option implementation plays a larger role in connecting to this empirical research in the coming years. An integration of the process considerations with the strategic content of real options, as well as more investigations of their combined implications, will be key to the appropriate translation and adaptation of concepts from financial economics into the realm of strategy and management (Bowman & Hurry, 1993; McGrath et al., 2004).

Second, it would be valuable to obtain primary data on firms, and even on actual decision makers' investment motives and preferences for real options analysis (e.g., Hartmann & Hassan, 2006), given that the empirical developments to date have tended to rely upon secondary data, and often at the coarse industry level. Data from reduced-form models have offered interesting and important results on the likelihood, timing, and structuring of investments, yet it would also be valuable to determine which aspects, if any, of real options theory truly build into managers' cognitive evaluation of information while making investments. In many cases it might be appropriate and convenient to impute the purchase, maintenance, exercise, or disposition of options, but such tests can aspire to offer more direct, granular evidence on these phenomena. For example, in the case of financial options, the signals received by agents are more clear cut for making exercise decisions (e.g., a price change on an organized market), yet managers presumably need to attend to different sources of uncertainty, and it would be interesting to understand which cues managers attend to and how organization matters.

Third, it is important to understand the various value creation and appropriation mechanisms working within real options. The framing of extant empirical studies is most typically on the side of the option purchaser or holder, yet the selling party at the other side of the exchange can appropriate the option value that may be created in the trade (see Chi, 2000). For instance, the fact that a firm acquires a target with valuable growth options may say little about whether the firm will capture value from such an exchange, since the option seller may have other alternatives and the value of options likely enters into the terms of the trade. More generally, with few exceptions, empirical studies have rarely attended to the costs of purchasing, holding onto, or exercising options, all of which shape the value that purchasers and sellers can capture. This notion suggests a need for empirical research to control for the costs and other unobserved heterogeneity related to options, and it also cautions against drawing universalistic conclusions on the benefits of real options.

Fourth, research on real options needs to be sensitive to competing explanations for findings when offering what often amount to consistency tests. This is all the more important considering recent conceptual advances as well as debates concerning the descriptive validity and normative value of real options in organizations. For example, the presence of real options is only one explanation for why firm behavior might depart from neoclassical investment theory, so studies that are better able to rule out other explanations for why firms persist in the face of negative signals would be valuable (e.g., decision biases, agency costs, other exit barriers, etc.) in order to conclude definitively that firms are rationally holding options open.

Fifth, future studies will need to continue to be able to tease apart different types of options, wherever possible, and address the falsifiability of tests of real options theory that either link uncertainty to investment likelihood or link other variables to firm outcomes. The former has already been discussed; as an example of the latter, consider the effects of a firm's ownership of its foreign subsidiaries. On the one hand, lower levels of ownership can enhance the within-country GOV of an investment. On the other, greater ownership and control may be required for system-wide optimization of the switching options the firm holds to reduce downside risk. As noted above, the combination of many different types of options and different underlying theoretical mechanisms (e.g., learning versus sub-additivity through overlaps in options) can be particularly challenging in work examining option portfolios.

Sixth, and related to the point just made, there is a need to investigate other types of options that firms trade, in particular, abandonment options and other puts. As research is devoted to these other options, there will be a corresponding need to develop and use outcome measures that are uniquely suited to a particular option. For example, Berger, Ofek, and Swary (1996) have developed an approach to valuing firms' abandonment options, and researchers may be able to apply this approach to certain strategy contexts such as M&A or corporate restructuring.

Seventh, we see considerable opportunities for research to deepen the empirical base in the streams discussed in our review. For example, within the stream on the timing and structuring of investment, researchers might examine other types of options that have received little attention (e.g., abandonment options and other puts), could study how the actual use of real options analysis affects firms' investment timing or structuring, and could also investigate exciting new application areas (e.g., corporate venture capital, IPOs, contracting, etc.). Within the research stream on the firm implications of real options, more attention might be given to providing guidance on the usage of general performance or risk measures to test real options theory, and the customized outcome measures discussed could be used in many other strategy contexts. In both of these areas, it is probably fair to say that the empirical developments are still at an early stage, and certainly the developments are uneven across the areas we have reviewed.

Finally, at a broader level, future research can combine other theories and perspectives, besides those previously studied, with real options to help bound the theory's predictions in empirical applications. For example, joining agency theory with real options analyses would also be valuable in order to better understand the potential uses or misuses of real options in organizations. In addition, incorporating game-theoretic insights into real options analyses has the potential to reconcile the strategy field's conflicting views of commitment versus flexibility as the sources of superior performance (Ghemawat & del Sol, 1998). As interest continues to grow in applying real options in strategic management, our belief is that empirical research along these lines can be of value in advancing the theory, both by probing its descriptive validity as well as by assessing its normative aspirations and claims of bridging corporate finance and strategy.

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PART III:
REAL OPTIONS AND STRATEGIC INVESTMENT DECISIONS

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STRATEGIC GROWTH OPTIONS IN NETWORK INDUSTRIES

Lihui Lin and Nalin Kulatilaka

ABSTRACT

Performance of firms in network industries depends much on the creation of standards around their technologies, products, or services. Establishing standards requires committing large, irreversible, upfront investment while demand remains uncertain. This paper focuses on the real options involved in this investment problem. The conventional real options literature recognizes the waiting-to-invest option where firms could avoid regret by waiting until at least some of the uncertainty is resolved. However, early commitment of network investment has vital strategic effects on shaping the expectations of potential users and inducing them to adopt the standard, thus creating a strategic growth option. We develop a simple model to explore the tradeoff between this strategic growth option and the waiting-to-invest option. We solve for the optimal investment rules and find that for high uncertainty, the strategic growth option often dominates the waiting-to-invest option and reduces the investment threshold. Furthermore, the intensity of network effect enhances the strategic growth option. Our results have important implications to the strategies of firms in technology industries.

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INTRODUCTION

Networks are increasingly dominating our life by changing the very nature of how we work and how we spend our leisure. Advances in communications and information technologies connect large populations of people, machines, and sensors to form a host of valuable networks. The digitized content coupled with this pervasive connectivity has spawned a menagerie of new services that touch our day-to-day life. Unlike in the case of normal goods, the value of network goods extends beyond the standalone (autarky) value to the user. Users of network goods reap increased utility from the ability to connect and collaborate with other users (network value). As a result, the value of a network to each user increases with the number of other users in the network.

This tremendous value potential can present very attractive investment opportunities to firms that build networks. The rush to build new networks, however, has repeatedly been followed by dramatic failures.[1] Builders of networks must commit large and irreversible investments well ahead of widespread customer adoption of unproven goods and services. In the early stages of a network's evolution, it will have few users and each user will realize only low levels of network benefits. As a result, users will remain unconvinced about the full value of the network good until the network reaches maturity. This adoption decision of users increases uncertainty regarding the potential demand for the network good. The uncertainty is exacerbated when multiple firms compete to establish a network standard and when multiple components in a complementary network system must be developed to deliver the network product.

Firms making investments in networks face not only uncertainties around the creation of value but also added uncertainties around the appropriation of value. Although the adoption of the network by each user increases the value of the network to every other user, users must not only take into account the current size of the network but also form expectations about the future growth of the network. This often leads to an adoption externality where even a monopolistic producer is unable to price the network good to reflect the full extent of the network effect. We examine the early commitment of investment as a credible way to convince users about the future size of the network and thus internalize the network externality.

Specifically, we examine the strategic effects of a firm's investment in a market characterized by network effects and uncertain demand. On the one hand, when facing uncertainty about the future market demand, postponing the commitment of an irreversible network investment has value, which is referred to as the *waiting-to-invest option* in conventional real options analysis. Investing before the uncertainty is resolved kills this option to wait. On the other hand, the immediate commitment to a network investment can have strategic benefits that act as an incentive to accelerate investment decisions. In other words, the prospect of establishing a network is a *growth option* for the investing firm. In particular, early commitment of investment into developing a network standard will raise users' expectations about the size of the market. Due to the strategic effects of the investment on users, we call this a *strategic growth option*.[2]

A substantial economics literature on network effects has addressed issues of optimal network size, pricing of network goods, welfare implications of networks, and network externalities. See Katz and Shapiro (1985, 1994), Leibowitz and Margolis (1994), and Economides (1996) for excellent surveys of the literature. However, these models tend to be set in a static setting and focus on equilibrium conditions. They also do not explicitly treat the effects of uncertainty.

The strategic effects of early investments for normal goods have been studied extensively in the literature (see Dixit, 1980 and Spence, 1984). More recently, real options models have included strategic effects under uncertainty (see Grenadier, 1996 and Kulatilaka & Perotti, 1998). In a related paper, Kulatilaka and Lin (2006) consider strategic effects of investments and licenses on potential competitors in an imperfectly competitive market. This paper studies the strategic effect of investments on users' expectations.

These strategic effects of investing in standards play a vital role in firm valuation. For instance, the timing of the investments, the intensity of the network effect, and the level of uncertainty affect the production levels, prices, and profitability. Whether one uses a conventional discounted cash flow (DCF) model or real-options based valuation model, the valuations hinge critically on the forecast profits and risk levels.[3] Our valuation approach recognizes the option value of waiting to invest. Unlike conventional real options models, however, we incorporate the impact of investment timing on the resulting consumer behavior by influencing expectations.

We develop a model where a firm has the monopoly right to invest to produce a network good, the demand of which is uncertain. We solve for the investment threshold as the expected demand that must be exceeded for the firm to invest immediately. We find that the investment threshold monotonically decreases with the intensity of the network effect. The impact of increased uncertainty on the threshold is ambiguous.

THE ECONOMIC IMPACT OF NETWORK GOODS

Networks conjure an image of a myriad of connections that provide physical links, which facilitate the movement of goods, people, or information between dispersed locations. Highway and rail systems facilitate the smooth and rapid movement of goods and people. Telephone networks enable people throughout the world to talk to each other. Most readers would recollect the days when only a handful of scientists had access to e-mail. Anyone outside this community would not find many friends or colleagues belonging to the network of e-mail users and would not find e-mail to be of much value. However, as the community of e-mail users grew to reach a larger population, individual users found e-mail to be increasingly valuable. It is the widespread adoption that brought about value of the network. As each new user joined the network, all existing users benefited from the ability to connect to the new user. This surge in value is referred to as *direct network effect*.

Direct network effects can also arise without physical connections between the users. Common standards, which establish logical connections between users, bring about a similar effect. For example, a particular word processor or spreadsheet program "connects" a network of users who can collaborate and share documents. As in the case of physically connected networks, as the community of users adhering to the common standard grows, so does the value to each user.

In yet other instances, networks are formed around systems of complementary goods or services (e.g., video game consoles and games, cars, gas stations, and repair shops). The literature characterizes such effects as *indirect network effects*. The mechanism of the network effect is indirect in that the more users of a standard, the greater the incentives for complementors to create more variety, and the increased variety enhances the value users gain from the complementary systems. Therefore, a similar network effect exists: as the total number of users increases, so does the value to each user. The proliferation of video game titles around a particular game console creates such a complementary system, where a network of users become "connected" and benefit from the proliferation of variety over time. The value of an operating system depends on the variety of software developed for it. Such complementary systems of a hardware/software paradigm prevail not only in technology industries, but also in markets such as cars/gas stations, credit cards/merchants, and durable equipment/repair services. The common theme between all of the above networks is that the value to each user grows with the number of users. Users of complementary networks also reap network benefits, but these benefits arise through a very different mechanism. As more users adopt a complementary network system, it leads to increased incentive to innovate, thus resulting in a proliferation of complementary components. Users benefit from this proliferation of variety. For instance, as more users adopted VHS players, more movies became available in the VHS format. Just as they derived utility from increased connectivity, users also derive utility from the increased variety.

Understanding the impact of network effects is vital to producers of a network good. An obvious economic effect of networks arises from the high fixed costs and very low (near zero) variable costs of production. As a result, producers experience increasing returns to scale for network goods and it has led to the emergence of regulated natural monopolies, such as telecommunications, electric power, railroads, and water. The tremendous user benefits of networks, however, can play an even more vital role when committing investments in networks.

Increased user benefits do not necessarily translate into higher prices for network goods or higher profits to the network investors. Network builders must cope with the troubling feature of adoption externalities that can prevent the capture of the value added from network effects. When a user joins the network, each existing user also stands to gain increased utility. The producer is not always able to reflect this effect in the price to pre-existing users. Therefore, it is vitally important to find mechanisms to convey the equilibrium size of the network to its potential users.

The focus of this paper is on such strategic aspects of investments in networks. We postulate situations in which the investment acts to internalize the network effect. Specifically, we modify the inverse demand function such that the price of the good is affected by the network effect. This allows us to study the impact of investment timing and network effects isolated from all the other network ramifications.

The demand for a network good can be represented by:

$$P(q, \theta) = \theta + v(q) - q \tag{1}$$

where q is the quantity demanded for the good. The random variable, θ, represents the maximum potential market demand for the standalone use of the network good, which is uncertain. We study the set of distribution functions of θ with a strictly positive support on θ where a higher mean implies first-order stochastic dominance. We refer to these distributions as *well-behaved distributions*.

The presence of network effects increases the value to users and their willingness to pay. We represent this network value by $v(q)$. It is to be noticed that this representation is general and allows network effects to arise from both connected (direct) and complementary (indirect) networks.

There is a growing literature about the form of the $v(q)$ function. A linear function of network value, $v(q) = \beta q$, is consistent with Metcalfe's Law (Gilder, 2000). The parameter β is the *intensity of the network effect*.[4] At the one extreme, for normal goods where users realize their entire value from the standalone use, $\beta = 0$. As β increases, more and more value comes from network effects. For networks with the same size, the higher the intensity of the network effect, the higher network value users gain from the network.

More generally, we know that network benefits tend to level off after the network reaches sufficiently large size. As the network grows, a user may not derive the same additional value from more users joining the network as he/she does when the network is small. Therefore, network effects can be modeled by a more general function of the form:

$$v(q) = \beta q^{\alpha}$$

The parameter $\alpha (0 < \alpha \leq 1)$ represents how quickly the network becomes saturated.[5] The higher α is, the less likely the network becomes saturated. It can also be interpreted as an indicator of a network's capacity: a high α suggests large network capacity. In our base case model, we assume that Metcalfe's Law holds, but we later consider this more general specification of network effects.

MODEL

Consider a single firm, M, having a monopoly over both the network investment opportunity and the product market. At $t = 0$, M has the opportunity to make an irreversible investment I, which enables the production of a network good at some future date, $t = 1$. We can think of this investment as a fixed "entry fee" that allows the firm to produce at time 1 when the market opens. For instance, firms may be able to signal their intent to users through investments in R&D, forging alliances for marketing and distribution channels or complementary goods, building capacity, or building brand image through advertising. At time 0, the demand parameter θ is uncertain and distributed on $(0, \infty)$, with expected value $E_0(\theta) = \theta_0 > 0$. θ is fully revealed at time 1.[6]

While such an investment can impact future production costs (e.g., learning), in this model we isolate its sole impact to be the credible communication of the size of the future network to potential users.[7] Specifically, by committing an investment at time 0 monopolist can credibly commit to an output level and convince potential users. The users will take into account the resulting equilibrium network size and the ensuing network benefits when making their purchase decision. The firm will thus choose equilibrium output level such that its time-1 profits are maximized with the recognition that users will accept this quantity. In the presence of network effects, the resulting higher quantity (larger network size) will lead users to be willing to pay a higher price, and thereby internalize the network effect. The investment becomes the mechanism through which the monopolist achieves the internalization of the network externality.

If the investment is not committed at time 0, the monopolist can still invest I at time 1 and produce the network good. However, users then must form their expectations on the size of the network exogenously.[8] Our equilibrium concept is that of fulfilled expectations equilibrium (FEE). The output choice in an FEE results in a smaller network.[9] The users, therefore, are less willing to pay for the network good due to a smaller anticipated network size, which leads to lower profits for the monopolist.

We assume that the unit cost remains constant regardless of the time of the investment. The unit cost is a combination of all production costs and may be a function of the output, which can be denoted by $k(q)$.[10] For a network good, $k(q)$ is likely to be decreasing in q, leading to increasing return to scale on the supply side. However, in order to isolate the network effects arising from the demand side, we assume the variable cost of production to be constant (i.e., $k(q) = k$).

We solve the model backward in time: first consider M's optimal production decisions at $t = 1$ for different scenarios, and then study the investment decision at $t = 0$.

STRATEGIC EFFECTS OF INVESTMENT ON PRODUCTION DECISIONS

When the firm makes its production decisions at $t = 1$, the uncertainty has resolved; therefore, the results we derive here are considered ex post outcome.

The profit function for the monopoly at time 1 is given by $\pi = q[\theta + v(q) - q - k]$. If M has made the investment I at time 0, it has convinced the users and can thereby optimize the output level by treating q as endogenous.[11] The output level is chosen by M, such that

$$q^* = \arg\max_q [q(\theta + v(q) - q - k)]$$

Table 1. Ex Post Outcomes: Quantity, Price, and Profit.

	Network Effects		No Network Effect (3)
	If M invests at time 0 (1)	If M does not invest at time 0 (2)	
Quantity	$q^* = (1/(2(1-\beta)))(\theta - k)$	$q^{**} = (1/(2-\beta))(\theta - k)$	$q^{***} = (1/2)(\theta - k)$
Price	$P^* = (1/2)(\theta + k)$	$P^{**} = (1/(2-\beta))\theta + (1-\beta)/(2-\beta)k$	$P^{***} = (1/2)(\theta + k)$
Profit	$\pi^* = (1/(4(1-\beta)))(\theta - k)^2$	$\pi^{**} = (1/(2-\beta)^2)(\theta - k)^2$	$\pi^{***} = (1/4)(\theta - k)^2$

The resulting equilibrium production level (q*), price (P*), and profit (π*) when $v(q) = \beta q$ are given in Column 1 of Table 1.

If M does not invest at time 0, then it no longer has an ability to credibly convince users about its future market power. Instead, users form expectations of the network size, q^e, and commit to pay a price based on this level of production. Therefore, M must take q^e as given in making the investment decision. In other words, the optimal output when M does not invest at time 0 is given by:

$$q^{**} = \arg\max_q [q(\theta + v(q^e) - q - k)]$$

We have $q^{**} = 1/2[\theta + v(q^e) - k]$. In FEE, the expected output equals the equilibrium output, i.e., $q^e = q^{**}$. Therefore, we can derive the equilibrium values when $v(q) = \beta q$, which are given in Column 2 of Table 1. Finally, for comparison purposes, we report the equilibrium quantities, prices, and profits earned by a monopolist in the absence of network effects in Column 3.

Comparing Columns 1 and 2 in Table 1 shows the impact of the investment timing decision. We see that investing at time 0 results in higher quantities and profits when compared with the case where investment is postponed ($q^* > q^{**}$, and $\pi^* > \pi^{**}$).[12] The firm will not produce if the realization of θ is lower than the production cost, k. This suggests that investing at time 0 provides M with an opportunity to expand production and earn higher profits, as long as the realized demand is sufficiently high. As we expect, the intensity of the network effect monotonically enhances the growth opportunity.

We also note that ignoring the network effect clearly leads to underestimated profits (compare Column 3 with Columns 1 or 2). The forecast quantities, prices, and profits are shown to differ on the assumptions regarding the network effect (the level of β). The severity of the underestimation increases with the intensity of the network effect.

STRATEGIC INVESTMENT DECISION

Although the immediate commitment of investment leads to higher profits, the investment requires an irreversible expenditure of I. If θ turns out to be less than k, the firm would regret having made the investment. If the firm does not invest immediately and wait until the uncertainty is resolved, it avoids investing in an unfavorable situation but also loses the opportunity of convincing users and earning higher profits in favorable situations. Therefore, the investment decision would be based on a comparison of the exante expected value of the firm under the two investment-timing strategies.

Since the focus of this paper is to study the strategic effect of investments, we make several stylizations in arriving at the value functions. First, the profits at time 1 are interpreted as the capitalized values of all future cash flows. Second, the value at time 0 is the discounted expected value of the time 1 capitalized profits. In order to isolate the strategic effect, we assume zero discount rate.[13]

The Waiting-to-Invest Option

To illustrate the value of the option to postpone the commitment of an investment (i.e., the waiting-to-invest option), we first consider the firm's investment decision if there were no strategic effect of early investment. Without the strategic effect on users' expectations, M's ex post profit would be given by that in Column 2 of Table 1, whether it invests at time 0 or time 1.

The discounted expected value when M makes the investment at $t = 0$ is obtained by taking the expectations over the region of positive profits and then netting out the investment.

$$V^I_{ns} = E_0\{\pi^{**}\}^+ - I = E_0\left\{\frac{1}{(2-\beta)^2}(\theta - k)^2\right\}^+ - I$$

If no investment is made at time 0, the investment and production decisions at $t = 1$ are made if and only if $\pi^{**} - I > 0$. Hence, the expected value of the investment is given by

$$V^{NI} = E_0\{\pi^{**} - I\}^+ = E_0\left\{\frac{1}{(2-\beta)^2}(\theta - k)^2 - I\right\}^+$$

Obviously, $V^{NI} > V^I_{ns}$. This is because by waiting the firm avoids regret in unfavorable conditions (when $\theta < k$). In other words, the firm gains value by postponing the investment until some uncertainty is resolved. This is the value of the waiting-to-invest option, recognized by conventional real options analysis.[14] In our model, the value of this waiting-to-invest option, denoted by V_{WTIO}, is given by

$$V_{\text{WTIO}} \equiv \text{Value of the waiting-to-invest option} = V^{NI} - V^{I}_{ns}$$

As a result, without the strategic effect, the firm always waits until time 1.

The Strategic Growth Option

We know that investing early does have strategic effects on users. With such effects, the firm's ex post profit is given by that in Column 1 of Table 1. The discounted expected value for investing at $t = 0$ is then:

$$V^I = E_0\{\pi^*\}^+ - I = E_0\left\{\frac{1}{4(1-\beta)}(\theta - k)^2\right\}^+ - I$$

Comparing V^I and V^I_{ns}, we see that the strategic effect of early investment allows the firm to earn higher profits. In other words, investing early provides the firm a growth option. Furthermore, the growth option here is *strategic*. While non-strategic growth options take market conditions as exogenously given, strategic growth options involve interactions between players in a market.[15] A strategic growth option occurs when an early investment influences other parties' behavior, and other parties' response results in a growth opportunity for the investing firm. Kulatilaka and Perotti (1998) provide an example of a strategic growth option where the leading firm's investment influences the follower firm's production choice. Here, the strategic aspect arises through the interaction between the firm and its potential customers: the firm's early commitment of investment convinces more potential users and therefore creates an opportunity for the firm to earn higher profits.

Furthermore, we can express the value of the strategic growth option as:

$$V_{\text{SGO}} \equiv \text{Value of the strategic growth option} = V^I - V^I_{ns}$$

Optimal Investment Decision and the Investment Threshold

Now we consider the firm's investment decision taking into account the effects of both the waiting-to-invest option and the strategic growth option.

The investment decision of the monopolist is based on a comparison of the value functions V^I and V^{NI}. When $V^I > V^{NI}$, M invests at time 0; when $V^I < V^{NI}$, M does not invest at time 0 but defers the decision to time 1 when the uncertainty is resolved and θ is realized.

From the real options point of view, the firm acquires a strategic growth option by investing immediately; however, doing so also kills the waiting-to-invest option. We know that $V^I = V^I_{ns} + V_{\text{SGO}}$, and $V^{NI} = V^I_{ns} + V_{\text{WTIO}}$; therefore, comparing V^I and V^{NI} is equivalent to comparing the value of these two options. The optimal investment decision depends on the relative value of the two options.

The values of V^I and V^{NI} depend on the expected demand, that is, the expected value of θ at time 0. We define the threshold level of the expected demand such that $V^I = V^{NI}$ as the investment threshold, denoted by θ_0^*.

In order to gain more insight into the characteristics of the investment threshold θ_0^*, we assume that θ is subject to a lognormal distribution: $\ln(\theta/\theta_0) \sim N[-(1/2)\sigma^2, \sigma^2]$, such that $E(\theta) = \theta_0$.[16] The shape parameter σ represents the uncertainty of future demand. The value functions can then be expressed as

$$V^I = \frac{1}{4(1-\beta)}\left[\theta_0^2 \exp(\sigma^2)\Phi\left(\frac{3}{2}\sigma - \frac{1}{\sigma}\ln\frac{k}{\theta_0}\right) - 2k\theta_0\Phi\left(\frac{1}{2}\sigma - \frac{1}{\sigma}\ln\frac{k}{\theta_0}\right) + k^2\Phi\left(-\frac{1}{2}\sigma - \frac{1}{\sigma}\ln\frac{k}{\theta_0}\right)\right] - I$$

$$V^{NI} = \frac{1}{(2-\beta)^2}\left[\theta_0^2 \exp(\sigma^2)\Phi\left(\frac{3}{2}\sigma - \frac{1}{\sigma}\ln\frac{d_1}{\theta_0}\right) - 2k\theta_0\Phi\left(\frac{1}{2}\sigma - \frac{1}{\sigma}\ln\frac{d_1}{\theta_0}\right)\right] + \left[\left(\frac{k}{2-\beta}\right)^2 - I\right]\Phi\left(-\frac{1}{2}\sigma - \frac{1}{\sigma}\ln\frac{d_1}{\theta_0}\right)$$

where $d_1 = k + (2-\beta)\sqrt{I}$.

Fig. 1 illustrates how the expected value functions of the firm under the two investing strategies, V^I and V^{NI}, decide the investment threshold, θ_0^*. Several features about these plots are worth noting. First, both functions are non-decreasing in θ_0. Second, since investing immediately incurs the initial investment, $V^I(0) < V^{NI}(0)$. It is also easy to show that $\lim_{\theta_0 \to \infty}(V^I(\theta_0) - V^{NI}(\theta_0)) > 0$. Hence, from the intermediate value theorem we know that there is a unique investment threshold, θ_0^*, at which investing immediately and waiting until time 1 have the same expected value, that is, $V^I(\theta_0^*) = V^{NI}(\theta_0^*)$. In other words, when the expected value of future demand equals

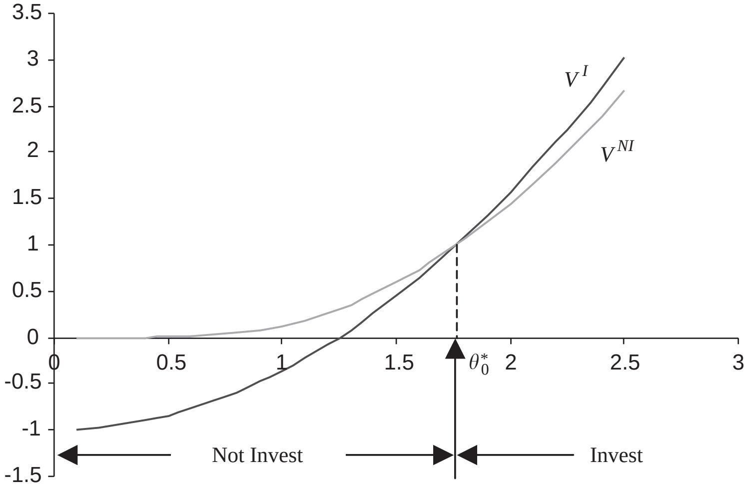

Fig. 1. Value Functions and Investment Threshold ($v(q) = \beta q$, $k = 0$, $I = 1$, $\beta = 0.5$, $\sigma = 0.5$).

this threshold level, the firm is indifferent between investing at $t = 0$ or postponing the decision to $t = 1$. Note that the strategic growth option and the waiting-to-invest option have the same value at the investment threshold.

Impacts of Network Intensity and Uncertainty

We now discuss the impact of the intensity of network effects, β, on the value functions and the investment decision.

Fig. 2 plots V^I and V^{NI} functions against θ_0 for two different values of β. It shows that when the network effect is more intense, both V^I and V^{NI} show greater value (i.e., higher β leads to higher V^I and V^{NI}). Fig. 2 further shows that the impact of the network intensity is stronger on V^I than on V^{NI}. Consequently, the investment threshold falls with rising network intensity, β.

The reason is as follows: First, based on the expression of V^I_{ns}, it can be easily proved that V^I_{ns} increases with β, that is, regardless of the options, higher network intensity increases the value of the investment. Second, higher network intensity leads to a larger increase in V^I than in V^I_{ns}, implying that the strategic growth option (V_{SGO}) becomes more valuable when the network effect intensifies. Third, we note that while V^{NI} does increase with β, the increase is smaller in magnitude than the increase of V^I_{ns}.

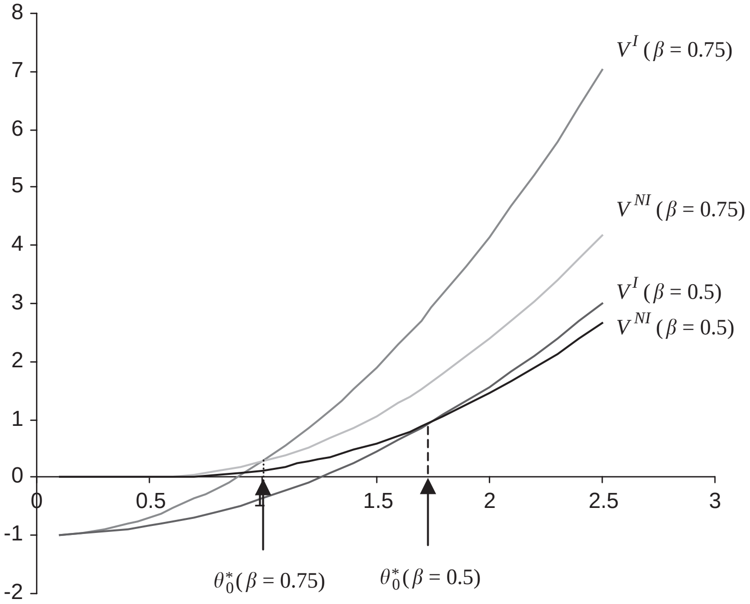

Fig. 2. Investment Threshold Decreases with Network Effect ($v(q) = \beta q$, $k = 0$, $I = 1$, $\sigma = 0.5$).

In other words, the waiting-to-invest option, in fact, decreases in value when network effect intensifies. Overall, higher network intensity makes the strategic growth option more valuable and the waiting-to-invest option less so, leading to a lower investment threshold. Intuitively, a more intense network effect makes the growth opportunity more attractive and leaves the firm with less incentive to wait.

Another important feature of our model is its ability to study the impact of uncertainty on the firm's value and the investment threshold. Fig. 3 plots the value functions against θ_0 for different values of σ when the intensity of network effect β is fixed: Panel (a) shows the case when β is relatively low ($\beta = 0.2$), while in Panel (b), β is relatively high ($\beta = 0.8$). We see that at any given level of network intensity, as uncertainty increases (σ increases from 0.1 to 0.6), both value functions, V^I and V^{NI}, shift upward. This is because both π^* and π^{**} are convex and differentiable in θ; therefore, by Jensen's inequality, a mean-preserving spread increases their expected value. This suggests that when demand is more uncertain, both the strategic growth

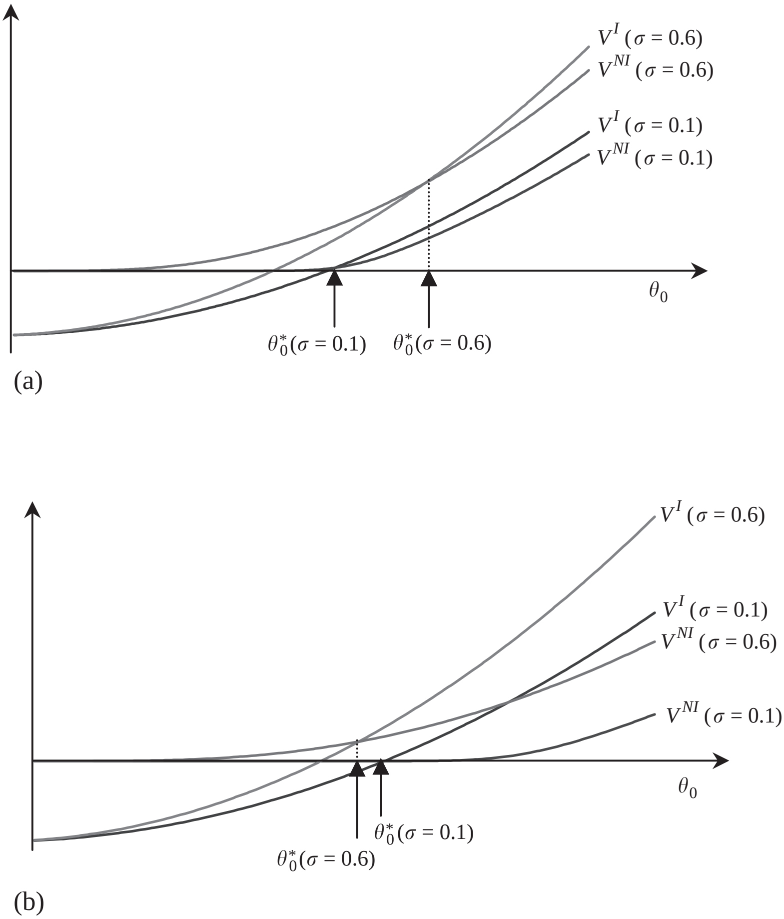

Fig. 3. Impact of Uncertainty ($v(q) = \beta q$, $k = 0$, $I = 1$); (a) $\beta = 0.2$; (b) $\beta = 0.8$.

option and the waiting-to-invest option are more valuable. The investment threshold then depends on the magnitude of the changes in these values.

When the intensity of network effect is low (Panel a of Fig. 3), the increase in the value of the strategic growth option due to higher uncertainty is smaller in magnitude than the increase in the value of the waiting-to-invest option. This leads to a higher investment threshold. Suppose at low uncertainty for a given expected demand parameter θ_0, M is indifferent between investing immediately and later (i.e., $V^I = V^{NI}$). When uncertainty increases, V^{NI} increases more than V^{I} does; therefore, for the given θ_0 M prefers to wait rather than to invest immediately. The demand parameter must reach some level higher than θ_0 for M to be indifferent between the two investment strategies again.

In contrast, when the intensity of network effect is high (Panel b of Fig. 3), more uncertainty results in an increase in the value of the strategic growth option that dominates the increase in the value of the waiting-to-invest option, leading to a lower investment threshold.

Overall, the impact of uncertainty on the investment threshold depends on the network effect. Fig. 4 presents the investment threshold under different levels of network intensity and uncertainty. Obviously, increasing network intensity lowers the investment threshold at any level of uncertainty. It is also clear that the investment threshold increases with uncertainty for networks with low intensity, but decreases for networks with high intensity. More interestingly, there is a regime change when the intensity of network effect is in the medium range (e.g., $\beta = 0.5$, 0.6): The investment threshold increases with uncertainty when uncertainty moves within the low range; however, as uncertainty further rises, the threshold starts to decrease with increasing uncertainty. In fact, even for networks with low intensity, as long as the uncertainty is sufficiently high (e.g., when $\sigma \gg 1$), the investment threshold decreases with uncertainty. This is because when the demand is

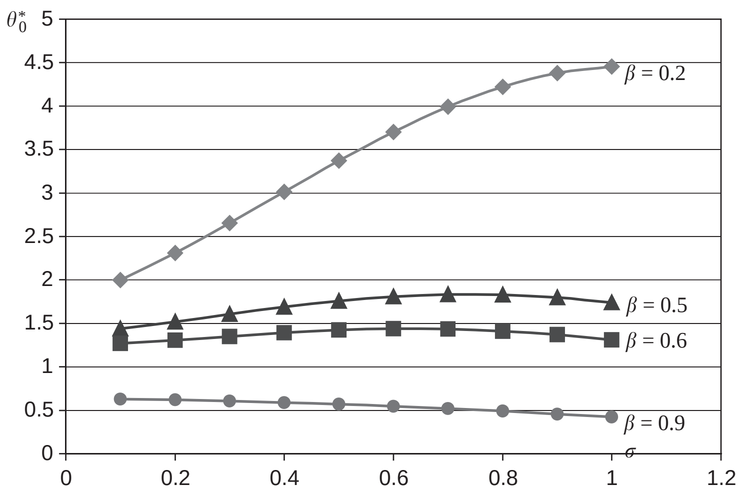

Fig. 4. Investment Threshold Changes with Network Intensity and Uncertainty ($v(q) = \beta q$, $k = 0$, $I = 1$).

extremely uncertain, strategic growth option dominates the waiting-to-invest option.[17]

These results have important implications for investment decisions. When investing in a network with low intensity, the investment rule is similar to that for traditional industries: the higher the uncertainty, the higher the expected demand must be to justify the investment. When the market is subject to intense network effects, however, the growth option becomes more valuable under high uncertainty, and investments should be committed even when the expected demand is very low.

The impact of network effect on the investment decision is most significant under high uncertainty. When the demand is highly uncertain, an increase in network intensity causes the investment threshold to decrease dramatically. This implies that underestimating the intensity of network effects will lead to undue caution with investment decisions and leave much money on the table. Conversely, overestimating the intensity of network effects often leads to undue optimism with investments.

The Investment Decision and Firm Value

Above we show that for each of the investment timing strategies (invest at time 0 or invest at time 1), the firm's value increases with both the network intensity and uncertainty. We also show that for any variation in parameters, the change in investment threshold is determined by the relative magnitude of the changes in the two value functions.

Table 2 shows the investment threshold θ_0^* and the value of the investment strategies at the threshold $V = V^I(\theta_0^*) = V^{NI}(\theta_0^*)$, for given levels of network intensity and uncertainty. At a given level of uncertainty, the investment threshold is lowered by increasing network intensity and the value of the firm at the investment threshold declines. Note that the only thing that has changed is the network value each user derives from one additional user, while the prospect of demand remains unchanged. Firms start to make investment at a lower threshold of expected demand, and therefore the value of the firm at the threshold is lower.

The value of the firm at the investment threshold, however, always increases with uncertainty, for any level of network intensity. This is easy to understand when the investment threshold also increases with uncertainty. Even when the threshold *decreases* with increasing uncertainty (when $\beta = 0.8$ or higher), the value of the firm at the threshold still increases with uncertainty. This is because higher uncertainty changes the prospect of

Table 2. Investment Threshold and Value of Firm ($v(q) = \beta q$, $k = 0$, $I = 1$).

σ	$\beta = 0.1$		$\beta = 0.3$		$\beta = 0.5$		$\beta = 0.7$		$\beta = 0.9$	
	θ_0^*	V	θ_0^*	V	θ_0^*	V	θ_0^*	V	θ_0^*	V
0.1	2.25	0.42	1.79	0.162	1.44	0.0472	1.09	0.0031	0.63	<0.001
0.2	2.74	1.166	2.00	0.488	1.52	0.198	1.10	0.0450	0.62	<0.001
0.3	3.30	2.310	2.23	0.939	1.61	0.411	1.11	0.126	0.61	0.0043
0.4	3.92	4.007	2.45	1.524	1.69	0.675	1.12	0.233	0.59	0.0175
0.5	4.57	6.454	2.67	2.261	1.76	0.987	1.13	0.359	0.57	0.0395
0.6	5.23	9.888	2.85	3.163	1.81	1.343	1.12	0.499	0.55	0.0682
0.7	5.86	14.58	3.00	4.239	1.83	1.740	1.10	0.648	0.52	0.101
0.8	6.43	20.80	3.10	5.493	1.83	2.171	1.07	0.804	0.49	0.137
0.9	6.91	28.84	3.14	6.918	1.80	2.630	1.02	0.963	0.46	0.174
1	7.27	38.94	3.13	8.499	1.74	3.106	0.97	1.121	0.42	0.210

market demand, and the firm must have a higher value to justify the investment in a more uncertain environment. These results have interesting implications. Suppose the expected demand is difficult for people outside the firm to estimate and they only observe firms' investment decisions. For a given uncertainty level, a firm is more likely to invest when the network effect is intense. However, the firm is also likely to have very low expected value.

In sum, high intensity of network effects lowers the investment threshold as well as the expected value of the firm at the investment threshold. Therefore, high propensity to invest with low returns is more likely to be seen in network industries.

EXTENSION: NETWORKS WITH POSSIBLE SATURATION

We now relax the assumption of Metcalfe's Law and use the more general functional form of network effects $v(q) = \beta q^{\alpha}$, where $0 < \alpha < 1$ represents how quickly the network becomes saturated.

It can be shown that with $v(q) = \beta q^{\alpha}$, investing at time 0 still constitutes acquiring a growth option ($q^* > q^{**} > q^{***}$ and $\pi^* > \pi^{**} > \pi^{***}$), the exercise of which also kills the option to wait. Fig. 5 shows the impacts of network saturation on investment threshold. We see that saturation effect does not change the investment decision qualitatively. The effects of network intensity

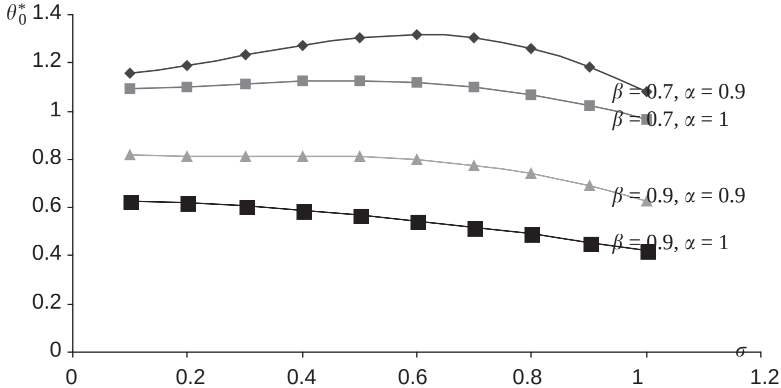

Fig. 5. Investment Threshold against Uncertainty for Different Network Intensity and Rate of Saturation ($v(q) = \beta q^{\alpha}$, $k = 0$, $I = 1$).

Table 3. Investment Threshold and Value of Firm ($v(q) = \beta q^{\alpha}$, $k = 0$, $I = 1$).

σ	$\beta = 0.7, \alpha = 1$		$\beta = 0.7, \alpha = 0.9$		$\beta = 0.9, \alpha = 1$		$\beta = 0.9, \alpha = 0.9$	
	θ_0^*	V	θ_0^*	V	θ_0^*	V	θ_0^*	V
0.1	1.09	0.0031	1.16	0.0158	0.63	<0.001	0.82	0.0014
0.2	1.10	0.0450	1.19	0.102	0.62	<0.001	0.81	0.0180
0.3	1.11	0.126	1.23	0.250	0.61	0.0043	0.81	0.0659
0.4	1.12	0.233	1.28	0.459	0.59	0.0175	0.81	0.148
0.5	1.13	0.359	1.31	0.744	0.57	0.0395	0.81	0.268
0.6	1.12	0.499	1.32	1.129	0.55	0.0682	0.80	0.434
0.7	1.10	0.648	1.30	1.644	0.52	0.101	0.78	0.656
0.8	1.07	0.804	1.26	2.312	0.49	0.137	0.74	0.944
0.9	1.02	0.963	1.18	1.319	0.46	0.174	0.69	1.297
1	0.97	1.121	1.08	4.098	0.42	0.210	0.63	1.705

and uncertainty remain the same in networks subject to saturation: the saturation effect in a network increases the investment threshold. The intuition is straightforward: saturation makes the growth option less valuable and therefore investment in such a network requires a higher expected demand.

Table 3 compares the investment threshold and the value of the firm in the case of possible network saturation with the case of no saturation. Not surprisingly, saturation effect increases not only the investment threshold but also the value of the firm at the threshold. We notice that the value of the firm at the investment threshold increases dramatically. However, it must be noted that such an increase in the value is due to the specification of the network effect: while we assume that with saturation the network value tends to level off as the network grows in size, the functional form for such network effect also implies that the network value rises rapidly when the network is small. The significant increase in the value of the firm at the investment threshold reflects the much higher value of the network when it is small.

In sum, when possible network saturation is taken into account, investments in networks require higher expected demand and such investments usually have higher value.

CONCLUDING REMARKS

This paper highlights the importance of strategic effects to firm's investment decisions. It suggests that DCF approach and conventional real options analysis must be modified to account for the strategic effects on market demand when valuing firms making investments in network standards.

Specifically, we find that a firm that is assured of being a continued monopoly has an incentive to commit to network investments before uncertainty about the future demand is resolved. The key feature of a network that drives our model is that each user experiences value from the presence of other users of the network good (network effect), in addition to the autarky value of consuming the standalone good. The benefit to early commitment comes from the credible communication to the users about the future size of the network and thereby, internalizing the adoption externality. We obtain the threshold level of expected demand above which the monopolist will commit the investment by trading off this strategic benefit of investment against the value of waiting to invest. Not surprisingly, the threshold level falls monotonically with increasing intensity of network effect. The somewhat surprising finding is that, as uncertainty regarding future demand grows the strategic value of early investment grows faster than the corresponding growth in the value of the option to wait, thus lowering the threshold level of expected demand.

These findings have important implications for a variety of business settings.[18] Perhaps the most compelling case is in electronic businesses that either provide new and unproven digital products and services, or have unproven business models. E-businesses also tend to have network effects and a crucial factor for success is to build up critical mass of users. Early investment is one way of convincing users.

One case in point is massively multiplayer online role-playing games (MMORPGs). Each new game can be considered a monopolist. Providers make significant upfront investments in hardware, software, and advertising to attract subscribers. Such investments are justified when the network effects are strong. Our results suggest that the investment threshold is quite low and insensitive to change in uncertainty when the intensity of network effects is high.

However, when an e-business has relatively low network effects, the investment threshold is high and sensitive to uncertainty. It implies that overestimating the network effect of a product or service tends to lead to wrong investment decisions often with devastating results. Perhaps many e-businesses failed for such a reason: the network effects from user interactions and complementary products and services were overestimated.

NOTES

1. There are strong parallels between the investment booms and the subsequent busts in the railroad and telegraph industries with the recent Internet bubble. See, for instance, Standage (1998) for enlightening historical case studies of the telegraph.

2. Although the focus is not on networks, Folta and O'Brien (2007) use acquisitions data to isolate and empirically examine the investment thresholds. They find that, while options to defer tend to raise the investment threshold, growth options lower such threshold. Our model allows for the explicit interplay between these two options.

3. For extensive surveys of firm valuation, see Brealey, Myers, and Allen (2005), and Copeland, Koller, and Murrin (2000).

4. See Lin and Kulatilaka (2006) for more elaboration.

5. When a network becomes saturated, more users in the network may lead to less network value for each user due to congestion. This may cause the network value to decline with the number of users, and may even become negative. In this paper, however, we assume that network effects are increasing in the size of the network.

6. Although we assume that uncertainty is fully resolved at time 1, the results only require that some information be revealed. Institutionally, we can think of time 1 as when the firm goes public and the value is capitalized in the stock price.

7. Katz and Shapiro (1985) consider a similar situation in which investment can be used to credibly communicate output levels in a multi-firm setting. In a related paper (Lin & Kulatilaka, 2006), we treat the role of investment as providing preemption of potential competitors with alternative standards.

8. For example, users can base their expectations on predictions made by government agencies, market research firms, or analysts.

9. Standard economics textbooks such as Mas-Colell, Whinston, and Green (1995, p. 439, 724) describe rational (fulfilled) expectation equilibria. Katz and Shapiro (1985) use a similar equilibrium concept in the context of network goods.

10. In the Kulatilaka and Perotti (1998) model, they allow for the early commitment of investment to lower $k(q)$.

11. The investment at time 0 is a way to credibly announce and commit to the output level.

12. These results hold true for more general network value functions where a network may become saturated, i.e., $v(q) = \beta q^{\alpha}$ $(0 < a < 1)$.

13. As with any option-pricing problem, the discounting is best performed by transforming it into its risk-neutral equivalent. We can also interpret our assumption of zero discount rate as that agents are risk neutral and the risk-free rate is normalized to zero.

14. For surveys of the real options literature, see Dixit and Pindyck (1994) and Amram and Kulatilaka (1999).

15. One example of non-strategic growth options is investments in flexible production technologies, which allow the firm to adjust its inputs in reaction to fluctuating input prices.

16. This allows us to perform mean-preserving changes to the level of uncertainty by examining the sensitivity to σ.

17. Kulatilaka and Perotti (1998) provide similar results, though the mechanism of the strategic growth option in that paper is different from that in the current paper.

18. See Reuer and Tong (2007) for a survey of strategic growth options.

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MARKET VERSUS MANAGERIAL VALUATIONS OF REAL OPTIONS

Timothy B. Folta and Jonathan P. O'Brien

ABSTRACT

We examine a central tenet of real option theory – whether real options influence managerial thresholds for investment. In contrast to prior studies that have focused on whether real options influence discrete investment decisions, our focus is on empirically isolating real options' effects on thresholds. In particular, we examine the real options inherent in acquisition decisions. Our model posits that there are good reasons why we might expect there to be information asymmetry around the value of real options. Accordingly, if managers have unique information about growth options we might expect to observe them lowering their thresholds, perhaps to the point where they are willing to accept negative market returns. We further expect that the degree of information asymmetry for firm-specific growth options should be higher than for industry-specific growth options. Finally, we believe that managerial thresholds will be more prone to influence from growth options than deferment options. While thresholds are unobservable, we are able to isolate the effects of real options on acquisition thresholds by borrowing a method used originally in labor economics to isolate the determinants of reservation wages. Using a sample of over 28,000 acquisitions in the U.S., we find strong support for the model. These findings suggest that firms with low thresholds may choose to acquire despite comparatively low expected performance.

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INTRODUCTION

In this paper we theoretically and empirically consider three questions pertaining to the value of real options. First, we examine whether capital markets value real options. This question has been pertinent since Myers (1977) postulated that the market value of a firm is a function of both its assets in place and its growth options. Using this logic, we might anticipate that investment decisions by the firm which bear upon its underlying real options would invoke changes in market valuations. It is an open question, however, to what extent and how quickly markets fully incorporate this information. Moreover, even if a firm initiates a growth option, it is possible that markets had anticipated this and already incorporated it into firm value.

We also consider whether real options may have a systematic influence on investment thresholds, where a threshold can be defined as the level of returns required to induce managers to make an investment. If the expected returns associated with an investment decision exceed the threshold level of returns, then firms will make the investment. We know of no work that has explicitly studied the relationship between real options and investment thresholds, despite the fact that theory suggests this relationship to be paramount. In fact, Dixit and Pindyck (1994, p. 422) have noted that "it is important to emphasize that the (real option) models do not describe investment per se, but rather the critical threshold required to trigger investment."

Finally, we also consider to what extent managerial valuations of real options differ from market valuations. At the heart of our study is the assumption that when managers recognize the value of real options, they may be willing to accept a lower level of short-term performance in order to gain access to these real options. That is, managers lower the thresholds required to trigger investment. There are reasons to believe that information asymmetry between managers and the market may (at least temporarily) create divergent valuations of growth opportunities, some of which may not be fully delineated or articulated at the time of a strategic action. These discrepant valuations may explain firm commitments even in the face of anticipated negative market reactions. By comparing how real options affect market returns versus the thresholds for investment, we can estimate the extent to which managerial valuations of real options systematically depart from the market's valuation.

As it is difficult to observe and measure the precise value of real options, past research has had to rely on estimations of reduced-form relationships between observed characteristics and strategic decisions, such as strategic investment (Folta, Johnson, & O'Brien, 2006), joint ventures (Kogut, 1991), entry (Folta & O'Brien, 2004), and acquisitions (Laamanen, 1999). As we explain below, such indirect tests are unable to distinguish whether observed patterns of strategic decisions resulted from hypothesized changes in how markets value real options, or from systematic but as yet unexplored variations in the value managers ascribe to real options.

This study extends a recent paper by Folta and O'Brien (2006) in two critical respects. First, Folta and O'Brien (2006) presented an exploratory investigation into how numerous factors, including real options, might impact thresholds for investment. This paper, in contrast, focuses exclusively on how real options influence investment thresholds. Accordingly, we offer several rationales for why real options might have an important *main* effect on thresholds, while Folta and O'Brien (2006) argued and demonstrated that real options had an *interactive* effect on thresholds. Moreover, we develop theory to explain why markets may be differentially effective at valuing deferment versus growth options. Second, while both studies empirically examine the determinants of acquisition thresholds, we consider and test the relative impact of real option variables on abnormal returns versus required thresholds. This allows us to more carefully discern whether managers give more weight to real options than markets.

Our findings suggest that firms with more current growth options have lower market returns around acquisition events. Furthermore, managers appear to give extra weight to growth options when making acquisitions by lowering their acquisition thresholds. In contrast, our results suggest that markets fully value deferment options. These findings have several important implications. First, regressing variables related to real options on market returns is likely to under-represent the true importance that managers place on growth options. Theories of asymmetric information seem especially pertinent when examining growth options. Second, regressing real option variables on discrete events (such as acquisitions) is helpful in diagnosing the total effect of growth options, but it obfuscates the divergent importance placed on growth options by markets versus managers.

REAL OPTIONS AND MARKET VALUE

To begin, it is critical to point out that surprisingly few studies have examined whether markets value a firm's real options. Bernardo and Chowdhry (2002) have speculated that the evidence surrounding the presence of a diversification discount is consistent with the view that diversified firms have exhausted more growth options. Tong and Reuer (2006) found that the variance in firm market-to-book ratios is largely explained by firm-level factors, and speculated that this evidence suggests that the value of growth options is determined predominantly by unique firm characteristics. Kumar (2005) found that volatility in industry shipments has a negative influence on abnormal returns for firms that divest joint ventures. Since volatility drives the value of real options, he reasons that this relationship is due to a loss in flexibility around the exercise of the option to acquire the joint venture partner.

It is curious why there is not more explicit attention to the relationship between market returns and real options. When Myers (1977) first distinguished between real assets (which have market values independent of the firm's investment strategy) and real options (which are opportunities to purchase real assets on possibly favorable terms) he recognized that the existence of valuable real options presumes some imperfections in the market: "There are no investment opportunities offering positive net present value (NPV) if product and factor markets are perfectly competitive and in continuous, long-run equilibrium. The value of real options reflects the possibility of rents or quasi-rents". Whether the firm specificity of the value of real options derives from experience curves, learning-by-doing, or because they are traded in imperfect secondary markets, there is a paradox in Myers (1977) explanation for why real options would have market value. The same factors that drive the firm-specific value of real options might also be difficult for individuals outside a firm to observe. For example, if managers know that their firm has certain valuable options available to them because of their absorptive capacity, markets may not accurately reflect the value of these options if they do not completely understand the extent and implications of the firm's absorptive capacity.

In this section we begin a discussion and hope to push theoretical development toward reconciling fundamental issues that bear on whether we can observe if the initiation or exercise of real options influence changes in market value. We believe a number of factors may bear upon this debate, including assumptions about market efficiency in valuing real options, understanding the different types of real options in a strategic decision, and understanding how real options may fundamentally alter the decision algorithm.

How Efficient are Markets at Valuing Real Options?

How long does it take the market to recognize the value of a firm's real options? An assumption of strong-form efficiency would suggest that security prices *immediately* reflect the value of any known information about a firm's real options. Of course, there is considerable debate about whether markets are strong-form, semistrong-form, or weak-form efficient. We do not attempt to enter into this debate, in part because there are no opportunities for real options to create value if product and factor markets are perfectly competitive. Rather, we speak to those readers who believe that markets are not strong-form efficient – that private information diffuses to the market over time. We believe there are at least two qualities of real options that influence the speed at which information about them diffuses: their iterative nature and their connection to firm-specific, intangible assets. Both these factors bear upon a researcher's ability to associate changes in market value to real options embedded in strategic activity.

Compound options involve complex series of nested investments. Often strategic investments in new products and geographic markets are of this sort. Initial foothold investments confer privileged access to information and opportunities for future investments, such as further product development stages or investments toward product commercialization. Recognizing that such multistage investments are compound options is a way to conceptualize the interdependencies associated with strategic decisions regarding path-dependent resources. We contend that the multistage and firm-specific nature of these investments raises the potential for information asymmetry between managers and outside market participants.[1] Managers may have unique insight into the unique interdependencies in the stages of investment and how their strategy and resources bear upon growth opportunities. As a result, relative to real assets, options on real assets may create a greater potential for information asymmetry.

A second reason why real options may be more predisposed (relative to real assets) toward information asymmetry between markets and managers is due to the nature of assets typically underlying real options. Myers (1977) has described a firm's real assets as being linked to its tangible assets, while a firm's real options as being linked predominantly to its intangible assets. He argued that while tangible assets are accumulated units of productive capacity, intangible assets are options to purchase additional units in future periods. Research has shown that firms that are rich in intangible assets tend to have more volatile market values and subject to a higher degree of information asymmetry (Aboody & Lev, 2000). A primary explanation for this is that in most firms "the disclosure of financial information does not provide a fair reflection of the true impact of intangible assets on their balance sheet, earnings and cash flow (Doppegeiter, Ul Islam, & Zoller, 2004)." Most external accounting systems do not require the disclosure of all intangible assets. Moreover, it is increasingly recognized that because of their uniqueness and inert nature, it is difficult to value intangible assets (Lev & Daum, 2004) and markets tend to underestimate their value (Doppegeiter et al., 2004).

Due either to the iterative character of real options or the nature of the assets underlying them, we suspect managers will have unique information (relative to markets) about their value. Of course, it is possible that managers do not themselves fully comprehend the value of their firms' real options. They may even be inclined to overvalue them if appropriate controls and incentives are not implemented.

Does Market Efficiency Vary by the Type of Real Option?

Further complicating our understanding of how real options inherent in investment decisions influence market value is that strategic investments usually embody more than one type of real option, and these options often interact with one another (Trigeorgis, 1993).[2] Let us consider the implications of multiple types of real options on market valuation in a single investment decision. Assume that a firm is considering making an investment in a new market to capitalize on opportunities to expand its market reach. A decision to invest can be characterized as the exercise of the option to defer investment, and to the extent this investment involves a sunk investment it represents a loss in flexibility. Consequently, the option exercise (i.e., market entry) results in the loss of an option and might be expected to decrease market value. A decision to invest, however, might also be characterized as the initiation of a growth option, with the sunk commitment required for entry representing the price of the option. If the growth option is worth more to the firm than it pays for it, then we would expect the firm's market value to increase with market entry. Kulatilaka and Perotti (1998) recognized that most strategic investments face this conflict between the growth and deferment options. Following their logic, Folta and O'Brien (2004) empirically discovered a non-monotonic effect of uncertainty on firm decisions to enter new markets. They found that industry uncertainty has a positive effect on entry at high levels of uncertainty, reflecting the belief that growth options dominate deferment options at high levels of uncertainty.

The implications of the conflict between growth and deferment options on market value are less understood. We conjecture that markets may be able to more easily value the loss of the deferment option. When entry occurs, this option is killed and estimating the value lost primarily entails ascertaining the sunk costs of entry and total uncertainty. In contrast, the growth option has only just been initiated, and estimating its value also entails estimating the myriad of ways that the investment might impact the firm's future cash flows, which will likely depend on many firm-specific factors. Thus, growth options may be more difficult for markets to value properly, and the fact that they tend to be firm-specific increases the potential for information asymmetry. As such, we might expect little information asymmetry regarding the exercise of deferment options, but more so around the initiation of growth options. Accordingly, we expect growth options to significantly influence managerial thresholds.

How Should We Empirically Isolate Real Option Effects in the Presence of Information Asymmetry?

Absent information asymmetry, it is reasonable to expect a firm's cost of capital will dictate its required threshold for entry, which should be equal to where an investment's NPV is equal to zero. Investments that yield positive or negative abnormal returns around an announcement date suggest positive or negative NPVs, respectively. Absent information asymmetry, managerial valuations of investment opportunities should generally conform to those of the market, and thus managers should invest if the expected market valuation of investment is equal to or greater than zero. However, when managers have better information than markets about the value of an investment, they may adjust their investment threshold to correspond to their belief about valuation. Thus, in the presence of information asymmetry, the revised decision criteria for an investment decision should reflect the potential for the investment threshold to vary from zero.

$$\text{Invest if}: \text{ expected market valuation} \geq \text{managerial investment threshold} \quad (1)$$

In this model, investment is determined by both the expected market returns and managerial thresholds. Real options may influence both expected market returns and threshold returns, and this simple model allows for separate and distinct effects for each. Thus, expected market returns need not exclusively determine investment. Rather, it is expected market returns relative to threshold returns that drive the investment decision.

Analysis of investment decisions requiring direct comparisons between the determinants of expected market returns and thresholds is subject to criticism on several grounds. First, expected market returns are nearly impossible to measure. For this reason, like all prior work we approximate expected market returns using actual market returns, R. Since $E(R) = R + e$, where e is equal to an error term, Eq. (1) can be revised as

$$\text{Invest if}: \quad R \geq \text{managerial investment threshold} - e \tag{2}$$

The second problem in estimating the threshold model Eq. (2) is that thresholds are difficult to observe and measure. The determinants of thresholds, such as the unique value that managers attach to a firm's real options, are also inherently difficult to quantify. So difficult, in fact, that explicit option pricing models are still infrequently employed in strategic contexts (Copeland & Keenan, 1998). In addition, attempts to compare whether the real options inherent in an investment decision are valued differently by markets versus managers must confront a basic endogenous selection problem: we do not observe any abnormal returns for investments where the expected returns fall below the managerial threshold. Thus, even if manager's acquisition thresholds could be adequately measured, we cannot observe the abnormal returns for all the potential acquisitions that do not occur. At best, one observes how real options influence abnormal returns for actual investments, making direct comparisons with how real options influence managerial thresholds impossible.

Researchers attempting to show that real options matter have confronted these challenges in a number of ways. Some have related abnormal returns and thresholds to observable characteristics in the firm or industry, and then base predictions of discrete events, such as entry, on those observed features. Folta and O'Brien (2006) have explained how this approach only takes into account the *total* effect of real options on the decision, and is relatively weak because it does not disentangle the effects associated with abnormal returns versus thresholds. To reconcile this dilemma and the others noted above, they advocate the use of an econometric technique: the censored regression (or tobit) with unobserved stochastic thresholds (Nelson, 1977; Smith, 1980; Maddala, 1983, pp. 174–178). This model is appropriate when the dependent variable is only observed when it falls above a particular level or threshold, and this threshold varies from observation to observation as a function of some independent variables.[3] Since this technique generates individual coefficients for both abnormal returns and thresholds, we can test hypotheses regarding the relationship of variables to each construct, and gain insight into the relative importance of real options to managers versus markets. We gain insight into the question of whether real options variables have different effects on market returns versus managerial thresholds.

Implications of Real Options on Required Thresholds

Based on the above discussion, there are strong reasons to believe that managerial decisions may be influenced by both their own investment thresholds and by the expected returns associated with real options. The following inferences are derived from the above discussion:

- Real options may influence both expected returns and managers' thresholds.
- If real options influence managers' thresholds, it is an indication that managers have divergent valuations than the market.
- Markets will be relatively more effective at valuing deferment options than growth options.
- Managers will lower their thresholds when their firms have more growth options.

RESEARCH METHOD

Data and Dependent Variables

Like Folta and O'Brien (2006), we test our threshold model in the context of acquisitions. While we employ the same data set and methods as their study, our study diverges in that we concentrate on the main effects of variables approximating real options. This focus is consistent with our theoretical impetus to explain why these main effects should have an impact on managerial thresholds, and not just abnormal returns. In contrast, the only real options effects argued for and tested in Folta and O'Brien (2006) were interaction effects with relatedness.

While a firm's threshold is not observable, it can be derived from comparisons of two observable outcomes: acquisitions and stock market returns around the acquisition events. A_{jkq} a binary variable, represents an acquisition decision of firm j ("1" if firm j acquired a target firm in three-digit industry k in quarter q, and "0" otherwise. The sample of acquisitions comes from the Security Data Company's (SDC) U.S. Mergers and Acquisitions Database. We included all acquisitions from the SDC data where (1) announcement dates fall between 1991 and 2000; (2) acquiring firms bid for a majority shares of a target firm; (3) the acquirer is a public firm listed on CRSP, Compustat, and Compact Disclosure during the event window; (4) acquisitions occurred in three-digit SICs less than 899, but excluding the financial sector (600–699); (5) we could obtain complete information on our independent variables from Compustat; and (6) we could obtain abnormal returns on acquisition event.[4] This led to a sample of 26,361 acquisitions.

To generate our sample of non-acquisitions, we use an approach similar to Harford (1999), who generated instances where firms made no acquisition attempts. Since we are interested in the characteristics of the target industry, our approach differs slightly in that we sample not only whether the firm makes an acquisition, but also every three-digit industry in which the firm has the potential to make an acquisition in a given quarter. This approach yields 77,717,760 potential acquisitions (52,512 firm per year $\times$ 4 quarters per year $\times$ 370 three-digit industries). Since A is "0" for all but 26,361 of these observations there is significant potential for estimation problems. To rectify this problem we use an approach similar to Montgomery and Hariharan (1991) and use state-based sampling (Manski & McFadden, 1981), where we take a random sample of the non-acquisitions. The sample of non-acquisitions in our study was created by randomly generating (with replacement) a sample of 42,000 firm-year observations, and then randomly assigning target industries to these observations.

For those firms that made acquisitions, market returns, R_{jk}, are generated from the cumulative abnormal return (CAR) associated with the acquisition announcement. The CARs were calculated with respect to a value-weighted market index.[5] The coefficients for the market model (i.e., each firm's beta) were estimated based on daily returns for the 255 trading days spanning days –300 through –46, relative to the announcement. The event window used to calculate the CAR was 3 days around the announcement date (i.e., $-1, +1$). The full sample of acquisitions had a mean CAR of 1.07% and median CAR of 0.34%. We eliminated 264 observations representing cases where abnormal returns were in the bottom 1% of the sample ($R < -20.59$) or the top 1% of the sample ($R > 28.95$) in order to facilitate the convergence of the model. This left us with a sample of 25,833 acquisitions having mean and median CARs of 0.85 and 0.34%, respectively.

Independent Variables

We identify variables to approximate growth options and deferment options. Our measure of growth options is the acquirer's market-to-book ratio. Myers (1977) argued that a high market-to-book ratio should be associated with a higher proportion of growth opportunities relative to assets in place. *Acquirer MB* was computed by using the firm market value (i.e., the market value of equity plus book value of debt) listed in Compustat I, then dividing by the total book value of assets. This variable should capture the firm-specific component of a firm's growth options, consistent with our earlier arguments that growth options are predominantly unique to a firm. To the extent that a firm's growth options are tied to intangible assets or complex iterative platform investments we might expect this variable to significantly influence managerial thresholds. We also use an industry-specific measure of growth options. *Target Industry MB* was computed by the median market-to-book ratio of all firms in the target industry. Since we expect both market-to-book variables to have their greatest impact on managerial thresholds at high levels, we also include their exponentials.

Next, following Folta and O'Brien (2004) we use industry volatility and its square term to distinguish between the effect of the deferment option and the industry-specific growth option, respectively. Although uncertainty has been modeled many different ways in the management literature, most approaches have been based on the volatility of some time series. Accordingly, we chose to model uncertainty based on industry-specific stock market indices, defined at the two-digit SIC level.[6] The primary benefit of this approach is that the underlying series considers all expected future profitability, and all sources of uncertainty that may impact that profitability. Following many studies in finance and economics (see Carruth, Dickerson, & Henley, 2000), we modeled the stock returns data using generalized autoregressive conditional heteroskedasticity (GARCH) models.[7] The main advantage to employing a GARCH model is that it produces a time varying estimate of the conditional variance of a time series, controlling for any linear trends that might exist in the data. The GARCH models were run on value-weighted industry portfolios that were developed from the monthly stock returns (adjusted for dividends and splits) for all firms in the CRSP database from 1950 to 2000. We average the monthly conditional variances to get quarterly figures. The variable *Target Industry Uncertainty* is then computed as the square root of the average quarterly conditional variance. (*Target Industry Uncertainty*)^2 is the average quarterly conditional variance. We introduce the exponential to capture the contrasting effects of the option to defer and grow. As argued by Kulatilaka and Perotti (1998), at low levels of uncertainty the option to defer should dominate, while at higher levels the option to grow should dominate.

As argued by Folta et al. (2006), deferment options should be a function not only of uncertainty, but the amount of capital required to enter an industry. We use *Target Industry Capital Intensity* to approximate the sunk cost required for entry, measured as the industry's median level of capital expenditures divided by its median sales. We also interact *Target Industry Uncertainty* with *Target Industry Capital Intensity* because the impact of sunk costs on the deferment option should escalate with uncertainty.

Like Folta and O'Brien (2006), we included a full set of firm and industry control variables, including variables to control for possible agency costs – a primary determinant of acquisition as found in the literature. Table 1 provides a brief description of the control variables and Table 2 provides descriptive statistics and correlations. All variables were standardized so we can more easily discern their relative impact.

Model Specification

The decision to acquire or not is based on the comparison of the two latent constructs of abnormal returns and the threshold. Thus, suppose the true abnormal returns and thresholds are

$$R_{jk} = \beta_1 X_{jk} + v \tag{3}$$

$$T_{jk} = \beta_2 X_{jk} + u \tag{4}$$

where X is a vector of attributes thought to influence abnormal returns and thresholds, respectively; β_1 and β_2 coefficient vectors, and v and u are normally distributed random variables. Even though the threshold, T_{jk}, cannot be observed for any observation, and the expected returns (R_{jk}) cannot be observed for non-acquisitions, the full structure of the acquisition decision can be estimated since we know the selection process (acquire if $R_{jk} \geq T_{jk}$) and if we can observe data or proxies for the expected returns to acquisitions. By maximizing the logarithm of the likelihood function with respect to these parameters we are able to obtain maximum likelihood estimates of the coefficients in Eqs. (3) and (4).

For a given observation in the sample, we observe A_{jk} (the binary variable representing acquisition), R_{jk} (the three-day stock market abnormal returns, only observed if $A_{jk} = 1$), and X_{jk} (the independent variables). The relevant parameters of the model are: β_1, the coefficients of the independent variables on abnormal returns; β_2, the coefficients of the independent variables on the threshold; s_1, the standard deviation of the disturbance (v) of the abnormal returns equation, which is assumed to be normally distributed; and s_2, the standard deviation of the disturbance (u) of the threshold equation. Consistent estimates of the coefficients of Eqs. (3) and (4) can be obtained as long as (i) an independent variable in the abnormal return equation is not in

Table 1. Control Variables, Definitions, and Sources.

Variable	Definition	Source
Merger waves	The total number of acquisitions in the target industry in the sample in the prior year	SDC
Target industry concentration	Four firm concentration ratio	Compustat
Target industry performance	The median operating income to assets ratio for all firms in a three-digit industry	Compustat
Systematic risk	The covariance between the returns on each industry's stock index and the market return over the previous 60 months	CRSP
Target industry R&D intensity	The ratio of total industry R&D to total industry assets	Compustat
Relatedness	The likelihood that a firm operating in industry *j* will also operate in industry *m*, corrected for the expected degree of relatedness under the null hypothesis that diversification is random, where *j* represents the closest business segment in firm *k*'s portfolio	Compustat
Acquirer diversification	The sum of squared shares of each of the firm's business segments	Compustat
Acquisition experience	The count of all total acquisitions that the focal firm made in the 3 years prior to the focal year	SDC
Acquirer ROA	Operating income/assets	Compustat
Acquirer size	The natural log of total acquirer sales	Compustat
Acquirer R&D intensity	Acquirer R&D expense/assets	Compustat
CEO duality	"1" if CEO is also Chairman of the Board; "0" otherwise	Compact disclosure
Inside ownership	Percent of stock owned by insiders	Compact disclosure
Number of large blockholders	The number of blockholders owning at least 5%	Compact disclosure
Financial slack	The total amount of cash and short-term investments that the firm holds subtracted from its total long-term debt, then dividing by total firm assets. This value is then subtracted from one so that larger values will be associated with more financial slack	Compustat
All cash	Equal to "1" if acquirer purchased with 100% cash, "0" otherwise	SDC
All equity	Equal to "1" if acquirer purchased with 100% equity, "0" otherwise	SDC

Table 2. Descriptive Statistics and Pearson Correlation Coefficients ($n = 67833$).

	Variable	Mean	Min.	Max.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Acquirer MB	0.00	−0.52	50.14																					
2	Target industry MB	0.00	−1.78	13.58	0.12																				
3	Target industry uncertainty	0.00	−1.62	18.76	0.06	0.14																			
4	(Target industry uncertainty)^2	0.00	−0.70	43.08	0.04	0.11	0.87																		
5	Target industry capital intensity	0.00	−0.94	85.02	−0.01	0.06	0.02	0.02																	
6	Target industry uncertainty × target industry capital intensity	0.00	−0.74	110.62	0.01	0.07	0.30	0.26	0.92																
7	Acquirer ROA	0.00	−241.62	2.86	0.11	0.45	0.16	0.11	0.00	0.04															
8	Acquisition experience	0.00	−0.53	12.80	−0.03	−0.09	0.23	0.16	0.00	0.07	−0.14														
9	Relatedness of target	0.00	−0.59	1.85	−0.07	−0.34	−0.20	−0.14	−0.22	−0.24	−0.35	0.09													
10	Merger waves	0.00	−0.28	10.84	0.03	0.15	0.00	−0.01	−0.11	−0.08	0.16	−0.16	−0.09												
11	Target industry concentration	0.00	−0.67	6.54	0.04	0.40	−0.10	−0.07	0.05	0.00	0.27	−0.14	−0.39	0.12											
12	Target industry ROA	0.00	−5.90	8.39	0.02	0.28	−0.06	−0.04	0.06	0.02	0.29	−0.17	−0.19	0.10	0.23										
13	Target industry beta	0.00	−9.76	6.47	−0.09	−0.01	0.03	0.02	0.01	0.02	0.00	−0.04	0.01	−0.01	−0.03	0.10									
14	Target industry R&D intensity	0.00	−0.24	13.05	0.00	0.13	0.03	0.02	0.02	0.02	0.14	−0.06	−0.09	0.03	0.04	0.25	0.17								
15	Acquirer sales	0.00	−4.56	2.90	−0.13	0.00	−0.01	−0.01	0.00	0.00	0.00	−0.01	0.00	0.01	0.01	0.02	0.02	0.02							
16	Acquirer diversification	0.00	−0.60	3.18	−0.17	0.03	−0.02	−0.01	−0.01	−0.01	0.05	−0.06	0.00	0.00	0.03	0.20	0.39	0.35	0.10						
17	Acquirer R&D intensity	0.00	−0.04	135.57	0.05	0.00	0.00	0.00	0.01	0.01	−0.01	0.00	0.00	0.00	0.01	−0.01	−0.02	−0.02	−0.02	−0.11					
18	CEO duality	0.00	−1.09	0.92	−0.01	0.02	−0.01	−0.01	0.00	0.00	0.03	−0.02	−0.01	0.01	0.02	0.07	0.09	0.08	0.01	0.16	−0.01				
19	Inside ownership	0.00	−0.83	3.53	0.05	−0.03	0.01	0.01	−0.02	−0.02	−0.02	0.03	0.02	0.02	−0.03	−0.06	−0.18	−0.15	−0.01	−0.28	0.00	−0.04			
20	(Inside ownership)^2	0.00	−0.50	5.07	0.04	−0.03	0.01	0.01	−0.02	−0.01	−0.02	0.02	0.02	0.01	−0.03	−0.06	−0.12	−0.12	−0.01	−0.20	0.00	−0.03	0.93		
21	Number of large blockholders	0.00	−1.32	6.63	−0.02	0.02	0.03	0.02	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.04	−0.09	0.00	0.01	0.00	0.01	0.04	0.05	−0.01	
22	Acquirer financial slack	0.00	−53.03	2.80	0.18	0.09	0.05	0.03	−0.03	−0.02	0.10	−0.01	−0.06	0.04	0.09	−0.05	−0.15	−0.13	−0.03	−0.27	0.06	−0.07	0.04	0.01	0.01

the threshold equation; or (ii) the covariance between v and u is 0 (Nelson, 1977). We imposed both restrictions.[8]

For a given observation, the probability of observing a non-acquisition is

$$\Phi\left(\frac{\sum(\beta_{2i} - \beta_{1i})X_i}{s_1^2 + s_2^2}\right) \tag{5}$$

where $\Phi(z)$ represents the normal cumulative distribution function. The probability of observing acquisition is

$$\frac{1}{s_1} Z\left(\frac{R_{jk} - \sum \beta_{1i}X_i}{s_1}\right)\Phi\left(\frac{R_{jk} - \sum \beta_{2i}X_i}{s_2}\right) \tag{6}$$

where $Z(A)$ is the unit normal density evaluated at A.

The likelihood function aggregates these probabilities by multiplying them over all of the observations in the sample. By taking the logarithmic transformation of this likelihood function, we then obtain the log-likelihood function. Finally, to account for the state-based nature of the sample, we weighted each term in the log likelihood function by the inverse of the ex ante probability of inclusion of the corresponding observation in the sample (Manski & Lerman, 1977). The weighted log-likelihood function can be written as

$$\begin{aligned} &\frac{1}{\tau}\sum_{A_{jk}=0} \ln\left(\frac{\sum(\beta_{2i} - \beta_{1i})X_i}{s_1^2 + s_2^2}\right) \\ &\quad + \frac{1}{\gamma}\sum_{A_{jk}=1} \ln\left(\frac{1}{s_1} Z\left(\frac{R_{jk} - \sum \beta_{1i}X_i}{s_1}\right)\Phi\left(\frac{R_{jk} - \sum \beta_{2i}X_i}{s_2}\right)\right) \end{aligned} \tag{7}$$

where γ represents the proportion of the population acquisitions in the sample, and τ represents the proportion of the population non-acquisitions in the sample.[9] This model was estimated in STATA 9.0.

RESULTS

Model Significance

Table 3 provides the output from the estimation of two of the equations. The first is a joint maximum likelihood estimation of abnormal returns (column 1) and managerial thresholds (column 2), and the second is a binary logit on acquisition (column 3). Our theoretical model posits that acquisition will occur when expected abnormal returns exceed the managerial threshold level of returns. Thus, a variable's ultimate impact on acquisition is a function of its relative impact on abnormal returns and the managerial threshold, respectively. Our contention is that if markets value real options around acquisition events we will observe significant effects of the real option variables on abnormal returns. If managers have different valuations of real options we will also observe a significant effect of the real option variables on the threshold. We will not discuss the findings relating to the control variables, as they have been given attention in Folta and O'Brien (2006).

Key Findings Relating to Growth Options

We expect that growth options will raise abnormal returns around the acquisition, and that managers will also lower their thresholds because of their unique information about their value. We use three variables to approximate growth options. We expect that our firm-specific measure (*Acquirer MB*) may better capture the potential for managers' unique information than our industry-specific measures (*Target Industry MB*, *Target Industry Uncertainty*, (*Target Industry Uncertainty*)^2), which should imply a larger threshold effect for the firm-specific measure. We tested whether all these variables approximating growth options jointly influence the threshold by a likelihood ratio test comparing the full model in Table 3 (columns 1 and 2) to an unreported model, which excludes them from the threshold component of the maximum likelihood equation. This test produced a chi-square statistic of 374.7 for 4 degrees of freedom, suggested that these growth option variables significantly ($p < 0.0001$) added to model fit. Next, we consider the significance of the individual coefficients relating to growth options.

The coefficient for the firm-specific measure of growth options, *Acquirer MB*, significantly influences market returns and managerial thresholds. We illustrate these relationships in Fig. 1. The variable has a negative effect on market returns. This finding is consistent with prior empirical research looking at acquisitions (Hyland & Diltz, 2002; Moeller, Schlingemann, & Stulz, 2004; Rosen, 2006) and theoretical research that suggests that acquisitions signal that the acquirer's internal investment opportunities are poor (Jovanovic & Braguinsky, 2004). Of course, our primary interest is in determining whether growth options influence managerial thresholds. We find that *Acquirer MB* has a negative effect on managerial thresholds. The negative relationship coincides with our view that acquiring managers may have

Table 3. Parameter Estimates of Abnormal Return, Managerial Threshold, and Acquisition.

Variables	Joint Maximum Likelihood Model				Binomial Logit on Acquisition[a]	
	CAR(−1, +1)		Managerial threshold			
	(1)		(2)		(3)	
	Coefficient	S.E.	Coefficient	S.E.	Coefficient	S.E.
Acquirer MB	−0.36***	(0.07)	−0.90***	(0.07)	0.11***	(0.01)
Target industry MB	0.28***	(0.06)	−0.22***	(0.05)	0.10***	(0.02)
Target industry uncertainty	−0.73***	(0.17)	0.18	(0.14)	−0.20***	(0.04)
(Target industry uncertainty)^2	0.58***	(0.14)	−0.06	(0.12)	0.15***	(0.02)
Target industry capital intensity	0.23	(0.25)	−0.55**	(0.20)	−0.12	(0.07)
Target industry uncertainty × target industry capital intensity	−1.29***	(0.31)	0.00	(0.25)	−0.24**	(0.09)
Merger waves	1.91***	(0.05)	−0.60***	(0.04)	2.39***	(0.08)
Target industry concentration	−0.36***	(0.07)	0.17**	(0.05)	−0.14***	(0.02)
Target industry ROA	−0.15*	(0.07)	0.19**	(0.06)	−0.17***	(0.02)
Systematic risk	0.86***	(0.06)	−0.19***	(0.05)	0.26***	(0.01)
Target industry R&D intensity	−0.37***	(0.05)	0.02	(0.04)	−0.03	(0.02)
Relatedness	9.96***	(0.09)	−1.55***	(0.04)	3.85***	(0.09)
Acquirer diversification	0.06	(0.05)	0.12**	(0.04)	0.07***	(0.01)
Acquisition experience	1.88***	(0.04)	−0.22***	(0.03)	0.60***	(0.02)
Acquirer ROA	6.71***	(0.48)	0.48	(0.40)	1.00***	(0.11)
Acquirer size	1.47***	(0.07)	0.17**	(0.06)	0.30***	(0.02)
Acquirer R&D intensity	0.11	(0.15)	0.23***	(0.06)	−0.05	(0.03)
CEO duality	0.77***	(0.05)	−0.14***	(0.04)	0.12***	(0.01)
Inside ownership	1.34***	(0.16)	−0.35**	(0.12)	0.21***	(0.04)
(Inside ownership)^2	−1.40***	(0.16)	0.48***	(0.12)	−0.22***	(0.04)
Number of large blockholders	0.26***	(0.05)	−0.13**	(0.04)	0.08***	(0.01)
Financial slack	−0.54***	(0.06)	−0.28***	(0.06)	0.03*	(0.02)
All cash	13.88***	(0.11)				
All equity	8.96***	(0.09)				
Log-likelihood	−211007.23				−19338.210	
N	67,833				67,833	

Note: All models include fixed year effects.
$^{*}p < 0.05$.
$^{**}p < 0.01$.
$^{***}p < 0.001$.
[a]Standardized coefficients.

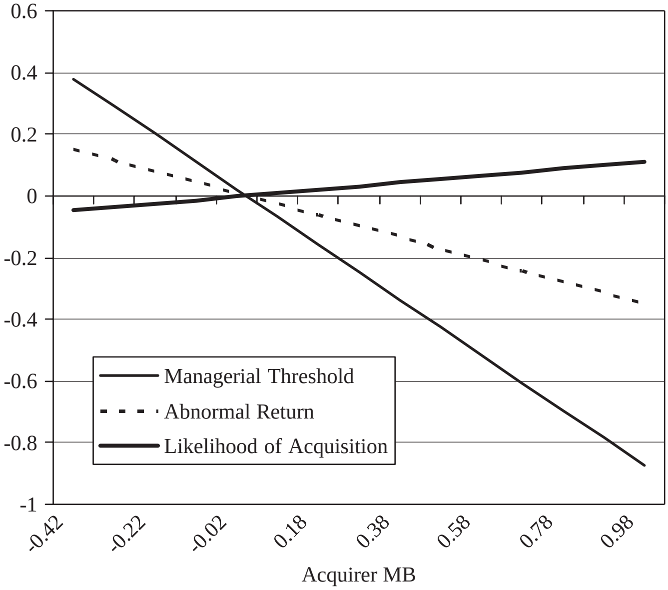

Fig. 1. Impact of Acquirer MB on Abnormal Returns (*R*), Managerial Thresholds (*T*), and the Likelihood of Acquisition (*A*) (Acquirer MB Ranges between its 5th and 95th Percentile), where $R =$ Acquirer MB $\times -0.36$; $T =$ Acquirer MB $\times -0.90$; and $A =$ Acquirer MB $\times 0.11$.

unique information about growth options tied to acquisitions. A glance at the size of the coefficients and at figure one suggests that the variable influences managerial thresholds more strongly than it influences market returns. This is an extraordinarily interesting finding as it suggests that managers ascribe over twice as much value to the growth options associated with the acquisition as does the market. A characteristic worth pointing out is that the point of intersection in figure one is where acquirers are indifferent to acquisition. This point coincides with an unstandardized market-to-book ratio of about 2.01 and falls in the 73 percentile of the sample. At low levels of *Acquirer MB*, managerial thresholds exceed market returns. This may suggest that for acquirers with small growth options, managers see little potential in capitalizing on growth opportunities. At higher levels of *Acquirer MB*, market returns increasingly exceed managerial thresholds. This suggests an increased likelihood of acquisition beyond the point of intersection, a finding which coincides with the results of the binary logit in column 3. What is clear from figure one is that the increased likelihood of

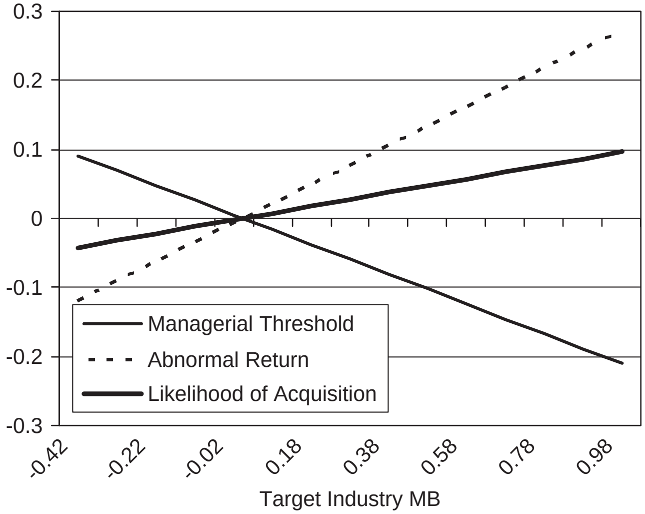

Fig. 2. Impact of Target Industry MB on Abnormal Returns (R), Managerial Thresholds (T), and the Likelihood of Acquisition (A) (Target Industry MB Ranges between its 5th and 95th Percentile), where $R =$ Target Industry MB $\times$ 0.28; $T =$ Target Industry MB $\times -0.22$; and $A =$ Target Industry MB $\times$ 0.10.

acquisition with higher levels of *Acquirer MB* is due to lower managerial thresholds, not higher market returns. We believe this evidence, in its entirety, is relatively strong support for our belief that acquiring managers are increasingly likely to lower thresholds when their firms have more growth options.

Next, we turn our attention to the coefficients for industry-specific growth options. *Target Industry MB* significantly influences both market returns and managerial thresholds. Fig. 2 illustrates the relationship of this variable to the three dependent variables. While the standardized coefficient (0.28) is larger for abnormal returns than the threshold (0.22), the difference is not significant. The variable has a positive impact on market returns, while it has a negative effect on managerial thresholds, as expected. It is worth comparing the relative impact of the industry-specific measures of growth options with the firm-specific effect. We can do this by comparing the size of the standardized coefficients. *Target Industry MB* has a significantly smaller effect on managerial thresholds than *Acquirer MB*. This result coincides with our belief that firm-specific growth options should create more potential for information asymmetry than industry-specific growth options.

The other measures of industry-specific growth options, *Target Industry Uncertainty* and (*Target Industry Uncertainty*)^2 do not have a significant influence on managerial thresholds. The coefficients do, however, suggest that uncertainty has a non-monotonic effect on abnormal returns. Abnormal returns decline at low levels of uncertainty and increase at high levels of uncertainty. This latter result can be interpreted at the scenarios where the growth option dominates the option to defer. These relationships are illustrated in Fig. 3, and suggest that the market fully anticipates the value accruing to growth options from industry uncertainty. In other words, managers do not gain any unique insight about the value of growth options from the industry uncertainty tied to acquisition opportunities.

Key Findings Relating to Deferment Options

We expect that deferment options will lower abnormal returns around the acquisition, but that managers will also raise their thresholds if they have unique information about their value. Relative to growth options, we believe there is less potential for unique information about deferment options. We use three variables to approximate deferment options, all of which are industry-specific measures (*Target Industry Uncertainty*, *Target Industry Capital Intensity*, and the interaction between the two). We tested whether all three variables plus (*Target Industry Uncertainty*)^2 jointly influence the threshold by a likelihood ratio test comparing the full model in Table 3 (columns 1 and 2) to an unreported model which excludes them from the threshold component of the maximum likelihood equation. This test produced a chi-square statistic of 65.2 for 4 degrees of freedom, suggesting that these deferment option variables significantly ($p<0.0001$) added to model fit. Next, we consider the significance of the individual coefficients relating to deferment options.

Target Industry Uncertainty lowers market returns but has no effect on managerial thresholds. Like its squared term, the market seems to fully anticipate the value lost by exercising the option to defer making an acquisition. We expect that the effect of uncertainty on the deferment option will be larger when acquisitions require larger sunk costs. As such, we expect that the interaction between Target Industry Capital Intensity and Target Industry Uncertainty will do a better job of capturing the value of the deferment option, as shown in prior studies. As expected, the interaction effect has a negative effect on abnormal returns. It does not, however, influence managerial thresholds. These findings are consistent with our view

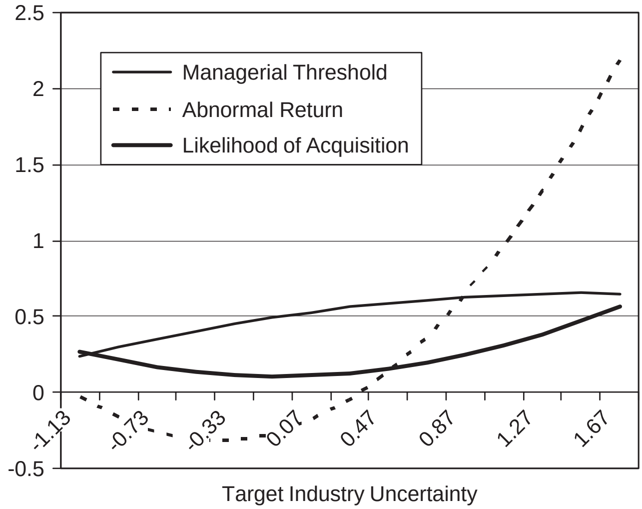

Fig. 3. Impact of Target Industry Uncertainty and Target Industry Capital Intensity on Abnormal Returns (R), Managerial Thresholds (T), and the Likelihood of Acquisition (A) (Target Industry Uncertainty Ranges between its 5th and 95th Percentile), where $R =$ Target Industry Uncertainty $\times -0.73 +$ (Target Industry Uncertainty)$^2 \times 0.58 +$ Target Industry Capital Intensity $\times 0.23 +$ Target Industry Uncertainty $\times$ Target Industry Capital Intensity $\times -1.29$; $T =$ Target Industry Uncertainty $\times 0.18 +$ (Target Industry Uncertainty)$^2 \times -0.06 +$ Target Industry Capital Intensity $\times -0.55 +$ Target Industry Uncertainty $\times$ Target Industry Capital Intensity $\times 0.00$; and $A =$ Target Industry Uncertainty $\times -0.20 +$ (Target Industry Uncertainty)$^2 \times 0.15 +$ Target Industry Capital Intensity $\times -0.12 +$ Target Industry Uncertainty $\times$ Target Industry Capital Intensity $\times -0.24$.

that markets are relatively efficient at recognizing the value of the option to defer, and that managers do not believe that they have unique information about their value.

DISCUSSION

Our primary purpose in this endeavor is to test to what extent managers and markets value real options differently. We have speculated that the value of real options is difficult for outsiders to discern because relative to real assets, real options tend to be tied to intangible resources. We also hypothesize that when real options require a series of iterative, nested moves, as with growth options, firm-specific knowledge of a firm's growth capability will accentuate the information asymmetry around real options.

Even though managerial thresholds are directly unobservable, the methodology we employ enables us to isolate their statistical determinants. Our results uniformly confirm our expectations. We have demonstrated that markets recognize some of the value in real options, but managers give "extra weight" to growth options when making acquisition decisions. They do so by lowering their thresholds – their required rate of return – to accommodate the real options accompanying acquisition decisions. This is interesting because even though firm's growth options reduce abnormal returns they increase the likelihood of acquisition. It lends credibility to the notion that there is a separate construct, managerial thresholds, which plays a mediating role, and that managers may have unique information relative to the market about the value of growth options.

We found no evidence that managers alter thresholds to accommodate deferment options. Our interpretation of this result is that managers recognize that markets will fully account for the value of deferment options because there is less potential for unique information about them. This finding is consistent with earlier work that has argued that all firms have access to the option to defer (Trigeorgis, 2000). It is worth pointing out that our measures for the deferment option were strictly industry-specific measures. While it is probably reasonable to assume that all firms are subject to the same exogenous uncertainty, it may not be reasonable to assume that all firms need to undertake the same sunk cost to acquire or enter an industry. For example, Folta et al. (2006) found evidence that deferment options are less consequential when firms enter related industries. Their explanation is that in the case of related entry firms can more easily redeploy assets if the initiative fails. This may suggest that while all firms have the option to defer, the value of the option will vary from firm to firm. Moreover, this implies that there is potential for managers to have unique insight into their firms' required scale of entry. Nevertheless, the scale for entry can probably be communicated more easily to the market at the time of investment, than the intricacies of the firm's future growth possibilities.

One important limitation of this work is that our decision model predicts that acquisition will occur when expected market returns exceed managerial thresholds. We did not measure expected market returns, but rather actual market returns. One implication of this is that if expected returns differed from actual returns the threshold relationships would pick up this error. For example, we might interpret the negative impact of growth options on the threshold as managers systematically overestimating the market's enthusiasm for the transaction when their firms have more growth options. Another potential interpretation is that managers of firms with larger growth options lower their thresholds so that they will gain personal benefits by making the acquisition. Indeed, these alternative interpretations were the basis of incorporating controls for agency relationships and addressed more completely in Folta and O'Brien (2006).

We believe our paper points to some interesting avenues of future research, some of which have been elaborated upon in this volume. We believe this paper is actually a nice complement to the Maritan and Alessandri (2007) paper. They argue that it is important to distinguish between firm- and industry-specific options because the potential for rent creation be different. Our results speak to that issue, and go beyond, by suggesting the mechanism by which these different types of options influence choice. Li, James, Madhavan, and Mahoney (2007) and others have suggested that we might examine whether real options theory explains exit from industries, or industry segment, or geographic regions. We might employ the threshold model to ascertain the determinants of exit thresholds. Finally, like Fister and Seth (2007) we believe there is great potential to understand to what extent governance mechanisms influence the initiation and exercise of real options.

In sum, we believe these findings point toward a need to disentangle how real options influence market values from managerial values. Building on Folta and O'Brien (2006), we have offered initial evidence on how real options influence thresholds using a method that was borne in labor economics. We believe it offers a fruitful avenue for future research.

NOTES

1. We note that our decision to dichotomize real options as firm-specific or industry-specific parallels the use as advocated by Tong and Reuer (2006) and Maritan and Allessandri (2007).

2. Our focus here is on the multiple options embodied in a single investment, rather than the interactions among a portfolio of options. We recognize there are important recent attempts to identify how a firm's portfolio of growth options may interact to influence a single investment decision.

3. This method has been used to estimate the determinants of actual and reservation wages in labor supply applications (Nelson, 1977), and the predictors of market transaction costs and internal organizational costs in studying decisions around organizational forms (Masten, Meehan, & Snyder, 1991). More recently, it has been used to estimate the determinants of entrepreneur's performance and

performance threshold in relation to the exit decision (Gimeno, Folta, Cooper, & Woo, 1997).

4. Condition 6 led to 2,739 acquisitions being dropped. We compared logit models with the full and reduced samples and they produced statistically identical results, leading us to believe that the reduced sample was not biased in any meaningful way.

5. A market index was preferred to size and market-to-book adjusted CARs because they can be biased (Rau & Vermaelen, 1998).

6. The two-digit level of analysis was used to calculate uncertainty because if we defined industries at the three-digit level, many of the industry portfolios displayed poor fit to the GARCH model that we used to compute uncertainty.

7. For more details on GARCH models, see Bollerslev (1986). Specifically, we employ a GARCH-M[1, 1] model.

8. The variables *All Cash* and *All Equity* were included in the abnormal returns equation but not the threshold equation.

9. We note that this correction was not made in Folta and O'Brien (2006), and so results differ slightly.

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DEFERRAL AND GROWTH OPTIONS UNDER SEQUENTIAL INNOVATION

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ABSTRACT

This paper examines the application of real option theory to sequential investment decision-making. In an effort to contribute to the development of criteria that discriminate between investments that confer growth options from those that confer deferral options, we introduce a conceptual model that explains technological adoption as a sequence of embedded options. Upon the introduction of each successive technological generation, a firm may either defer investment and wait for the arrival of a future generation or invest immediately to obtain experience that provides a claim on adoption of subsequent generations. We propose that deferral and growth option value is dependent on the magnitude, frequency, and uncertainty of inter-generational change, and the nature of rivalry.

INTRODUCTION

Real option theory has shown promise as a useful framework for evaluating investment decisions under uncertainty (Dixit & Pindyck, 1994; Trigeorgis,

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1998; Amram & Kulatilaka, 1999; Copeland & Antikarov, 2001). In contrast to traditional discounted cash flow techniques, the real option approach recognizes that managers are capable of reacting flexibly to changing market conditions and that risk may vary over different investment stages. When investments are at least partially irreversible, traditional decision rules based on discounted cash flows may fail to account for the benefits of sequential decision-making in response to the arrival of new information. Real option logic provides a method for evaluating the benefit associated with the opportunity to react flexibly. Numerous types of real options have been identified in the literature, including the option to defer, the option to stage investment, the option to alter operating scale, the option to abandon operations, the option to switch inputs or outputs, and the option to grow (Trigeorgis, 1998, pp. 2–3).

While the early real options literature emphasizes the value associated with deferring investment in the face of uncertainty (e.g., McDonald & Siegel, 1986), more recent work focuses on growth options that provide the ability to expand in the future (e.g., Pindyck, 1988; Kulatilaka & Perotti, 1998). The logic underpinning both deferral and growth options infers that traditional (discounted cash flow) investment theory fails to account for the value of flexibility under uncertainty, yet the two types of options recognize different sources for this value. Deferral option logic highlights the benefits of waiting for new information to arrive (McDonald & Siegel, 1986). In contrast, growth option logic stresses the value associated with early investments that provide platforms for future, follow-on investment. This ambiguity makes it possible to apply the theory to develop fully contradictory recommendations. For example, when considering entry into a new market, option theory can be used to support a decision to delay investment until uncertainty is resolved (McDonald & Siegel, 1986) or to enter early and create future growth options (Kogut, 1991; McGrath, 1997; Pindyck, 1988; Kulatilaka & Perotti, 1998).

It is our contention that the difficulty in distinguishing, ex ante, between different sources of option value has limited the contribution of real option theory to strategic management. A fundamental issue in the field of strategic management is the relationship between firm conduct and competitive advantage (Rumelt, Schendel, & Teece, 1994). Existing theory suggests that competitive advantage is most likely to be realized in market sectors where competition is constrained (Porter, 1980) or in "thin" factor markets where information asymmetry or other ex ante barriers to competition provide opportunities to access or develop resources below their market value (Barney, 1986; Peteraf, 1993). Existing work also describes how both early

(Lieberman & Montgomery, 1988) and late (Lieberman & Montgomery, 1998) investment may affect the ability to pursue these sources of competitive advantage. If real option theory can be sufficiently developed to provide insight in securing competitive advantage based on the timing (early or late) or nature (reversible or irreversible) of investment, it can contribute significantly to ongoing conversations within the strategy domain – possibly by suggesting linkages with existing theories of competitive advantage.

The objective of this chapter is to propose a set of criteria to distinguish between situations that are more or less likely to impart growth or deferral option value. We do so both conceptually and through an examination of technology adoption decisions in environments characterized by continual technical progress. In such situations, managers are often confronted with serial introductions of new technologies that either extend or replace previous versions. By adopting today, the firm faces the risk that a better technology may become available tomorrow and possibly render the original technology obsolete. While waiting would avoid this risk, it does so at the opportunity cost of utilizing the technology in the interim. The adoption decision therefore involves consideration not only of the technology available immediately, but also expectations regarding the timing and attributes of a future innovation. For example, Sayers (1950) documented the influence of such expectations on the adoption of competing engine technologies in ship building in the early 20th century (as quoted by Rosenberg, 1976, p. 530):

> There were times, between the wars, when marine engineering was changing in such a rapid yet uncertain way that firms in the highly competitive shipping industry delayed investment in the replacement of old high-cost engines by the new low-cost engines. In the middle 'twenties progress was rapid in all three propulsion methods – the reciprocating steam-engine, the geared steam-turbine and the diesel motor. Minor variations are said to have brought the number of possible combination types up to nearly a hundred. For some classes of ships there was momentarily very little to choose between several of these combinations, and shipowners were inclined to postpone placing orders until a little more experience and perhaps further invention had shown which types would be holding the field over the next ten years. Put in economic terms, the shipowners' position was that, though total costs of new engines might already be less than running costs of old engines, the profit on engines of 1923 build might be wiped out by the appearance in 1924 of even lower-cost engines, the purchase of which would allow a competitor (who had postponed the decision) to cut freights further. Also there was uncertainty as to which of the two types of 1923 engine would prove to work at lower cost. If shipowner A installed engine X, and shipowner B installed engine Y, whose costs in 1923 appeared to equal those of X, a year's experience might show that in fact Y costs were much lower than X costs, in which event shipowner A would have done better to wait until 1924 before installing new engines.

The following passage by Adams and Dirlam (1966) also cited by Rosenberg in his 1976 article (p. 531) illustrates a similar dilemma faced by managers of U.S. Steel Corporation in deciding whether to adopt a new steel-making process:

> U.S. Steel conceded that ''some form of oxygen steel-making will undoubtedly become an important feature in steelmaking in this country,'' but it declined to say when or whether to commit itself to introducing this innovation. Indeed, three years later, *Fortune* still pictured the Corporation as confronted by ''painfully difficult choices between competing alternatives – for example, whether to spend large sums for cost reduction *now* [1960], in effect committing the company to *present* technology, or to stall for time in order to capitalize on a new and perhaps far superior technology that may be available in a few years.''

The more recent Nucor case (Ghemawat, 1997; Christensen, 1997) illustrates how prior investments and uncertainty regarding the value of future products or technologies affect the attractiveness of subsequent opportunities. During the late 1980s, Nucor, a small steel manufacturer, decided to invest in a new and uncertain compact strip production process at a new ''mini-mill'' steel plant to be constructed in Crawfordsville, Indiana. Reports indicate that there were a number of severe start-up problems at this new plant and that initial financial returns on this investment were modest. Subsequent improvements to the process and the mini-mill concept created opportunities for dramatically improved performance, however. Firms such as Nucor that invested early in mini-mill technology gained experience that enabled them to quickly expand their stake in the new technology (for example, Nucor opened its second mini-mill plant in Hickman Arkansas, at a much lower cost than that required to open the Crawfordsville plant). In contrast, companies that deferred investment in the new process quickly fell behind and struggled to apply the rapidly improving technology in their own operations.

Similar investment decisions are increasingly common in contemporary high-technology markets such as semiconductors, software, and pharmaceuticals. When there are expectations of continued technological advance, managers often must decide between ''keeping their options open'' by deferring investment and ''securing a stake'' by committing at least some funds to explore a promising new technical trajectory. Because real option theory addresses both sides of this dilemma, technology adoption under sequential innovation provides the opportunity to identify situations where growth or deferral options dominate.

In the next section we briefly review the technology adoption literature and comment on the implications of real option logic for decision-making under sequential innovation. In section theory development, we relate growth and deferral option logic to technology adoption. In section empirical context, we outline an empirical strategy for identifying deferral and growth options in technology migration choices. A concluding section discusses the implications of our propositions and identifies avenues for future research. This discussion also serves to illustrate the broader applicability of our approach in research on strategic choice.

GROWTH AND DEFERRAL OPTIONS

A real option is analogous to a financial ''call'' option (Black & Scholes, 1973), which gives an investor the right, but not the obligation, to purchase a valuable asset (such as a share of stock) on a future (expiration) date at a certain (exercise) price. This ''option'' feature creates an asymmetry in the distribution of returns – by purchasing an option, the owner gains access to greater upside potential than downside exposure. At a future date, management may terminate the investment or take steps to fully exploit future positive outcomes (i.e., exercise the option). As in financial option theory, the value of the flexibility provided by the ability to selectively act on an initial investment depends critically on the value of the underlying asset, the cost to exercise the option, uncertainty regarding the future value of the underlying asset, the duration of time until the right to selectively act expires, and the expected cost of capital.

Growth and deferral options illustrate two principal means through which flexibility may affect investment decisions and their timing. Growth options characterize expenditures that create follow-on opportunities that may or may not subsequently be exploited. Such options are particularly relevant in high technology and R&D based industries where multiple opportunities arise from the development of a single infrastructure or platform (e.g., Myers, 1977; Kester, 1984). In such environments, small initial investments in exploratory research, pilot production, or early generations of a new product or technology may furnish a preferential claim or ''platform'' for future favorable investments (Kim & Kogut, 1996). This preferential claim is often based on the ability to transfer experiential learning from early investments into later projects or to preempt competition, possibly by developing brand loyalty with influential customer segments. Since the value of subsequent investment is contingent on the earlier investment decision, early investment can be considered as the entry price for the opportunity to participate in the expected sequence of subsequent related projects. A growth option differs from a first mover advantage conceptually due to the emphases by the former on the opportunity to stage investment over time and on the opportunity to reduce risk by reacting flexibly to changing environmental conditions.

A number of recent papers in the strategic management literature describe how uncertainty affects the growth option value associated with early investments. For instance, Kogut (1991) and Kogut and Kulatilaka (1994, 2001) explore the option value associated with investing in "platform" capabilities from which firms may respond more readily to future changes in their external environment. Similarly, McGrath and Nerkar (2004) find that pharmaceutical firms are more likely to create an option (by taking out a patent) in a new area of exploration when the "upside-potential" is large. The conceptual link between early investments, uncertainty, and growth option value has also been used to justify investment in international markets (Chang, 1995) and international joint ventures (Reuer & Tong, 2005) and establishing standards in industries exhibiting network effects (Lin & Kulatilaka, 2007).

Option theory has also been used to describe how risk may be mitigated by delaying or deferring investment. In industries such as resource extraction, deferral options are often associated with an initial payment such as a lease or license that grants the right to delay development of a plot of land or oil field. Development would be postponed until favorable environmental conditions such as high demand or low interest rates emerge (Kemna, 1993). Ordinarily a deferral option requires no expenditure to initiate, however, but simply bears upon the optimal timing of an irreversible investment. If the firm was to make an irreversible commitment under uncertainty, it would forfeit the possibility that it would not make the investment if unfavorable information would later arrive – therein lies the deferral option. The cost of the deferral option is comprised of the foregone marginal benefits that the firm would realize had it made the initial investment. Costs to delay foregone cash flows or possible entry by rival firms must be weighed against the benefits of receiving new information, therefore. Given estimates that in established industries such as chemicals, pharmaceuticals, petroleum, and electronics as few as 20% of R&D projects result in economically successful products or processes (Mansfield, Rapoport, Schnee, Wagner, & Hamburger, 1971), the option to defer or stage investment is likely to be a valuable source of flexibility (Dixit & Pindyck, 1994; McDonald & Siegel, 1986; Pindyck, 1991). Consistent with this view, several studies citing the option to defer have reported results linking higher levels of uncertainty with lower levels of investment (Campa & Goldberg, 1995) and a reduced probability of foreign market entry (Campa, 1993).

Theoretical models have been developed to analyze the effect of growth and deferral options on investment decision-making. Pindyck (1988) analyzes production capacity choice and expansion decisions when investments are irreversible and market demand is uncertain. In Pindyck's model, the cost of an immediate investment includes the lost option value of forestalling or averting the investment should adverse information emerge. The model also recognizes that under uncertain demand, plant expansion provides a growth option to add additional capacity later should positive market conditions occur. Considering these opposing options and modeling the firm's investment capacity choice as a series of incremental investment decisions, Pindyck shows that the greater the demand uncertainty, the higher the threshold demand must be to justify an irreversible investment. Greater uncertainty is also associated with a higher optimum level of investment, suggesting that growth option value associated with capacity investment is increasing in uncertainty. Based on these model outcomes, Pindyck concludes that irreversibility and unpredictable demand serves as a deterrent in initial plant investment.

Kulatilaka and Perotti (1998) conduct a second analysis of the effect of growth and deferral option value on investment. Their work expands Pindyck's approach by considering the strategic (preemptive) effect of investment under imperfect competition. They show that when possible preemption is taken into account, investment in an initial growth option can result in greater ex post profits relative to investment deferral. Even though the value of the deferral option is shown to be increasing in uncertainty, this increase is smaller than that of the growth option when there are significant preemptive effects associated with the initial growth option. When preemptive effects are small however, deferral option value increases at a higher rate than growth option value under increasing uncertainty. Kulatilaka and Perotti's model thus implies that the effect of uncertainty on the relative values of growth and deferral options is ambiguous.

Lin and Kulatilaka (2007) consider the preemptive implications of network effects on the relative values of growth and deferral options in industries where the creation of standards is important. In their model, early investment generates network externalities that shapes the expectations of consumers and encourages them to adopt the initial investor's technology. Under these conditions, Lin and Kulatilaka find that growth option value is magnified relative to deferral option value. When network effects are strong, growth options dominate deferral options under high uncertainty.

Despite the modeling efforts outlined above, empirical studies of real options attempting to reconcile conflicting prescriptions of real options theory regarding the timing of adoption or investment are rare. Folta and O'Brien (2004) is a notable exception. Their study examines the conflict between the effect of deferral and growth option logic on market entry decisions. Following Kulatilaka and Perotti (1998), they argue that growth options are more sensitive to uncertainty because (a) first mover advantages associated with market entry create greater upside potential, and (b) deferral options are bounded by the total amount of the irreversible investment required to enter (whereas growth options are not subject to an upper bound). Deferral option logic dominates when uncertainty is "low" and growth option logic dominates when uncertainty is "high," thereby generating a non-monotonic relationship between uncertainty and the entry decision. Folta and O'Brien also consider several factors and their effect on the uncertainty and entry relationship, such as the degree of "irreversibility" of the initial entry investment, the level of the initial investment, and the extent to which entry produces an early-mover competitive advantage.

Consistent with their hypothesis that the value of deferral options typically exceeds the value of growth options, Folta and O'Brien find that uncertainty negatively affects the probability of entry throughout most of the range of measured uncertainty in a pooled cross-sectional analysis of 17,897 firms observed from 1980 to 1999. Under very high levels of uncertainty (above the 93rd percentile in their study) however, the value of growth options overshadows the value of deferral options. In industries where early-mover advantage is substantial, the authors find that growth options become valuable at significantly lower levels of uncertainty. Support for their hypothesis regarding the effect of irreversibility on the uncertainty-entry relationship is nonetheless mixed.

While Folta and O'Brien's results are illuminating, their empirical analysis is limited to determining whether the degree of uncertainty or irreversibility (as proxied by the degree of investment in intangibles or inverse financial leverage) affects the decision to enter a new market. Their data do not allow them to observe whether a firm actually deferred investment from one period to the next or made early-stage option investments that were exercised with follow-on investments in a subsequent stage, issues that are central in the adoption of new technologies.

THEORY DEVELOPMENT

The preceding section describes the potentially conflicting prescriptions offered by real option theory and suggests that the comparative importance of growth and deferral options is likely to vary with contextual factors. In this and the following section we develop criteria that may be used to distinguish between situations that favor growth or deferral option value and outline a methodology to empirically test these predictions in environments characterized by sequential investment. Our model incorporates two technological generations, an existing technology currently available for adoption ("current technology") and a potentially more advanced technology expected to arrive sometime in the future ("future technology"). The model also considers two decisions, (a) whether and when to adopt the current technology, and (b) whether to adopt the future technology. We strive to contribute to the discussion regarding criteria that affect the relative significance of growth and deferral options by examining how differences in expectations regarding the value of the future technology, uncertainty in the values of the current and future technologies, the arrival time of the future technology, and the relatedness between the current and future technology are likely to affect investment at the two decision points.

The first criterion for discriminating between situations that offer greater growth or deferral option value highlights the importance of identifying the underlying source of uncertainty. A well-known insight from real option theory is that option value is positively correlated with increasing uncertainty – higher uncertainty increases the "upside" potential of the focal investment with no corresponding increase in "downside" risk. Deferral and growth options differ, however, on the object of the uncertainty. The "uncertainty" of interest in a deferral option is the variance in the value of the current technological opportunity. A deferral option's value is equal to the opportunity cost of irreversibly investing in a current technology of uncertain value today. This opportunity cost increases with the likelihood of outcomes that negatively influence the value of the current technology. In contrast, the objective of a growth option investment is to maximize the potential value captured from the future technology. As long as a mechanism to maintain a preferential claim on follow-on investments exists, the value of a growth option increases with the upside potential or uncertainty in the future technology's value.

Uncertainty in the values of the current and future technologies may or may not be related. If the current and future technologies are strong substitutes then changes in the value of the future technology will directly influence the value of the current technology. In this case, variations in the values of the two technologies are co-determined and it is appropriate to use a single measure of uncertainty when considering the two investment decisions. In terms of option values, higher uncertainty in the value of the future technology lowers the option value of deferring investment in the current technology, while increasing its growth option value. On the other hand, if the future technology represents only a weak substitute (e.g., when it provides an incremental advance over the current technology), then changes in the value of the future technology have a limited effect on the value of the current technology. Under this condition, there is little relation between the distribution of potential values of the two technologies and the proper application of deferral or growth option logic will require an assessment of different notions of "uncertainty."

A second condition that may distinguish between deferral and growth options involves the mechanism used to secure a claim on the opportunity to act flexibly in the future. Deferral option value is determined by the opportunity to make a different decision should new information arrive that affects the relative value of the focal investment compared to the set of alternative investment opportunities. This requires trading off potential first mover advantages and immediate cash flows associated with early investment against the advantages of a potentially lower purchase price or the arrival of potential alternative investments. The mechanisms that provide this opportunity are those that mitigate the loss of potential first mover advantages (e.g., ownership of complementary assets) and contextual factors (e.g., a limited opportunity environment) that affect the number and attractiveness of alternative investments.

Growth option value, in contrast, is dependent on the establishment of a preferential claim to invest in a future opportunity. In the basic setup for a growth option, (a) a firm identifies a new investment trajectory and expends some relatively fixed and presumably small price for pursuing that investment trajectory (i.e., an option purchase), (b) information arrives over time changing the level of uncertainty regarding the value of the new investment trajectory, and (c) in response to this information, the firm either exercises its option by investing fully or discontinues the project. A critical mechanism in this model is the action that insures that any advantage vis-à-vis the follow-on opportunity is not competed away when uncertainty is favorably resolved. It is often argued that this preferential claim is based on the ability to access proprietary information or develop deep knowledge regarding the follow-on opportunity. For instance, firms may use minority equity or joint venture investments to privately ascertain the management quality and growth prospects of a potential acquisition target (Folta, 1998; Kogut, 1991).

The different means of value creation emphasized in growth and deferral option logic suggests that it is possible to identify situations that favor one type of option over its alternative. As mentioned above, the expected value of a deferral option is determined by the opportunity cost of immediately investing in the current technology. This opportunity cost is driven by the supply and demand for critical resources that would be exhausted through immediate investment in the current technology. As these critical resources become scarce or the number of potential alternative investment projects increases, the opportunity cost of committing and the deferral option value also increase. The ability to capture value through a growth option requires the existence of a preferential claim on value created through the favorable resolution of uncertainty regarding the future technology. The strength of this claim is significantly influenced by the nature of the two technologies. If the future technology is considered a competence enhancing innovation, then the knowledge gained via experience with the current technology will be applicable to the use of the future technology, providing investors in the current technology with a preferential claim on investment in the future technology.

The expected arrival time of the future opportunity renders a third method to distinguish between deferral and growth option value. For both financial and real options, the time to expiration affects investors' cumulative exposure to uncertainty and the expected opportunity cost of investing capital in alternative interest bearing investments. The influence of time on the value of real options is more complex, however. As discussed above, for an investment to operate as a real growth option, the value derived from the future follow-on investment must be contingent on making the initial investment and a mechanism must exist that protects the advantage created by the initial investment. In financial options this mechanism is the legal contract associated with the option purchase. In a real growth option, maintaining a preferential claim on the value derived from a future technology is likely to require ongoing investment. For instance, it may be necessary to invest in R&D or monitoring programs to facilitate "absorption" of the future technology, survey the relative viability of alternatives, or assess the willingness to pay by customers for output generated by the future technology. The accumulation of such ongoing costs directly reduces the value of the growth option – its expected value is therefore likely to decrease the more distant the forecasted arrival time of the future technology.

EMPIRICAL CONTEXT

The preceding discussion describes the role of expectations regarding the source of uncertainty, the claim on upside value, and duration in growth and deferral option value. In this section we outline a methodology to empirically test these predictions based on observable behavior in environments characterized by sequential technological investment. We utilize the classification of adoption strategies developed by Grenadier and Weiss (1997). Their model incorporates two technological generations, an existing technology currently available for adoption ("current technology"), and a more advanced technology expected to arrive sometime in the future ("future technology"). A firm immediately adopting both the current and the future technology is termed a "compulsive" adopter. A firm that immediately adopts the current technology, but does not adopt the second generation, is considered to be following a "buy-and-hold" strategy. A firm that waits until the arrival of the future technology prior to adopting the current technology is considered to be adopting a "laggard" strategy. A firm that declines to adopt the current generation of technology, but adopts the future generation is considered to be enacting a "leapfrog" strategy. A firm that does not adopt either technology is termed a "bystander" (we do not consider this final possibility in our analysis) Fig. 1 depicts the adoption strategies classified by Grenadier and Weiss (1997).

The logic underpinning our analysis begins by first considering the adoption decision for the currently available technology. If the expected benefits exceed expected costs, the firm may adopt this technology. Upon the emergence of a new technology, the firm may upgrade to the new technology or remain with the current technology. The firm's decision to adopt the current technology, therefore, turns not only on the direct value of the current technology, but also on the value of the embedded option to upgrade to the future technology when it arrives, and any strategic benefit it would obtain from a first-mover advantage. The claim on this upgrade option value may be generated by knowledge gained by learning from using the current technology that is applicable to the new technology. For example, firms with experience in the current generation may be able to leverage trouble-shooting and problem-solving skills, expertise regarding the technical feasibility of fabricating products with different fabrication and assembly techniques, or informal cross-functional and cross-facility contacts (Clark & Fujimoto, 1991; Leonard-Barton, 1995) into the future generation. Experience in the current technology may therefore lower the cost of adopting the future technology through the establishment and refinement of appropriate information filters, communications channels, routines, and procedures (e.g., Cyert & March, 1963; Arrow, 1974; Nelson & Winter, 1982; Henderson & Clark, 1990). The embedded upgrade option associated with adoption of the current technology can therefore be viewed as a future growth option.

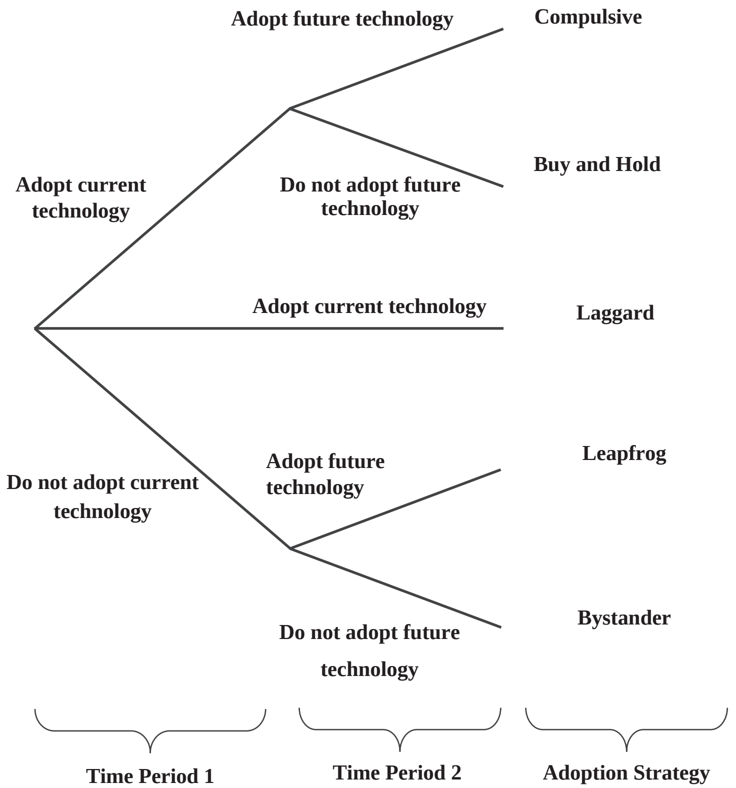

Fig. 1. Potential Timing of Investments in Current or Future Technology.

The firm may alternatively elect to defer adoption until the future technology arrives. At that time, the firm has three choices: (1) adopt the future technology outright, (2) adopt the old (formerly current) technology, or (3) do neither. The option to defer has value if there is a positive probability that the future technology would represent a drastic innovation that would threaten the value of the current technology. To the extent that the firm could adopt the current technology at a discounted cost upon arrival of the future technology, the incentive to delay adoption would also be increased. Potential costs of switching to the current technology may also deter adoption. For example, Kogut and Kulatilaka (2001) argue that an organization's difficulty in costlessly revisiting or reversing an adoption decision may deter application of the technology in the first place. Other switching costs such as network effects may also make it difficult for a firm to shift to a different technology in some industries (Lin & Kulatilaka, 2007). Lastly, any preemptive effects from prior adoption by rivals may discourage or delay adoption.

We collapse the relationships described immediately above and in the prior section into dimensions that capture the expected value of the flexibility to adopt potential follow-on technologies and the expected value associated with deferring investment. The strategies are presented in two panels that comprise Table 1. The top panel describes situations where subsequent generations of a technology are expected to provide drastic improvements in price and performance over the current technology and leverage capabilities that are utilized in the current technology. Such technological advances have been termed "radical" (e.g., Henderson, 1993, p. 250) and represent significant improvements along a single technical trajectory (Dosi, 1982). The lower panel depicts instances where improvements in the future technology are sufficiently moderate so that the current technology is expected to be competitive with the future technology. Henderson (1993, p. 250) refers to such innovations as "incremental." Following Henderson (1993), we acknowledge that the incentive to invest in innovation is affected by both market power and organizational capabilities.

To capture both time and variance components in classifying uncertainty, we follow the taxonomy developed by Luehrman (1998). At one extreme, when a new generation of technology is expected to arrive quickly and/or the technology's value is relatively certain, the environment is characterized as exhibiting low "cumulative volatility" (Luehrman, 1998). The left column in both the upper and lower panels of Table 1 represents such situations. In the right column, a greater period of time is expected to pass prior to the arrival of the subsequent generation and/or the value of the future technology is highly uncertain, thus corresponding to high cumulative volatility. The two rows in

Table 1. Technology Adoption Strategy Predictions.

	Low Cumulative Volatility	High Cumulative Volatility
Technologies are substitutes		
Competence enhancing	Leapfrog	Compulsive
Competence destroying		
Technologies are not substitutes		
Competence enhancing		
Competence destroying	Laggard	Buy and hold

both the upper and lower panel portray the expected value of the future technology relative to the current technology and depict whether capabilities necessary to utilize the current technology are applicable to effectively employing the future technology (i.e., the future technology is competency enhancing or competency destroying). The contents of each cell depict the technology migration strategy that is predicted to occur based on an evaluation of the growth and deferral option value expected in each situation.

The cell in the top left corner of the upper panel in the table describes circumstances where future innovations are (a) economically drastic, (b) rapidly, but predictably, introduced, and (c) draw on similar knowledge bases. Since innovations in the upper panel are substitutes for the current technology, the future technology is likely to drastically reduce the value of the current technology. The lack of variability in the value and arrival time of the future technology limits the value of the option to upgrade to the new technology. Moreover, the short expected time until the arrival of the future technology reduces the opportunity for a firm to recoup its investment in the current technology. While the use of similar skills to those that would be employed if a firm adopted the prior generation implies the existence of a strong claim on any potential growth option value, low cumulative volatility suggests that any latent option value is limited. Thus, firms positioned in the top-left cell are less likely to adopt the current technology and more likely to adopt the future technology – they are expected to follow a leapfrogging strategy. The option to defer adoption of the current technology dominates the growth option in this situation.

The lower panel describes situations where the future technology is not expected to be a strong substitute for the current technology. The expectation of relatively minor cost or quality improvements suggests that the current technology will remain competitive with the future technology, thus reducing the likelihood that the future technology will be adopted. The lower left cell in this panel describes environments in which the future technology is rapidly and predictably introduced and requires different skills to use. The high degree of confidence regarding the value of the future technology as well as the expectation that the future technology will arrive in the near future implies that there is little growth option value associated with the current technology. Moreover, firms that delay adoption of the current technology until arrival of the future technology may be able to take advantage of reductions in the cost of adopting the current technology. In addition, the expectation that use of the future technology will draw upon a new knowledge base severely limits inter-generational knowledge spillovers. In this situation therefore, a laggard strategy is implied. As with the leapfrogging strategy, deferral option value exceeds growth option value of adoption of the current technology in this case.

The cell in the top right corner of the upper panel in the table represents settings in which the likelihood and timing of introduction of a future technology is unpredictable over an extended period of time. Moreover, effective adoption of such a technology requires skills consistent with those employed along the current technical trajectory and the technology is expected to provide a significant performance improvement over the preceding generation. Since the future technology represents a drastic improvement over the current technology, it is likely that it will be adopted upon its introduction. The net effect of the expectation of the future technology on investment in the current generation, however, requires one to tradeoff the cost of cannibalization implied by the eventual introduction of a drastically superior technology against the opportunity to develop skills that may eventually be applied to a future technology of uncertain value. To the extent that the slow change implied by the expected long duration of time until the arrival of the future technology mitigates the expected costs of cannibalization, managers facing this scenario are more likely adopt the current technology. A compulsive adoption strategy is therefore predicted. In contrast to the two strategies above, a compulsive strategy is associated with higher growth than deferral option value for current technology adoption.

The cell located in the lower right-hand corner of the lower panel in Table 1 illustrates situations where the future technology is expected to provide a marginal, but highly uncertain, performance benefit. The anticipated marginal performance benefit indicates that the threat of cannibalization is low, increasing the value of the current technology while reducing the probable value of the future technology. The high level of uncertainty regarding this expectation, nevertheless, suggests the existence of potential growth option value. This potential growth option value is mitigated by the anticipated need for new skills in the future technology. The lack of a common skill base across the current and future technologies suggest there will be few opportunities to lever competencies across generations and that adoption of the current technology will not provide a strong, preferential claim on the future technology. While the ceiling imposed on the expected value of the future technology limits a firm's ability to capture growth option value via investment in the current technology, the relatively long duration of time that the current technology is able to generate returns encourages its immediate adoption, thus also limiting deferral option value. Since the values of both deferral and growth options are likely to be modest, firms in this situation are likely to employ a buy and hold technology strategy.

The final four cells in Table 1 illustrate circumstances that are not amenable to real option analysis. The two empty cells in the upper panel portray situations reminiscent of competence destroying technological discontinuities in the airline, cement, and mini-computer industries discussed by Tushman and Anderson (1986). In these settings, the future innovation is expected to provide a significant improvement over the existing technology using very different skills. Given the lack of learning spillovers or other factors that may provide a preferential claim on the new technology, the investment implications for the current technology are unclear. The empty cells in the lower panel illustrate circumstances where the future technology is expected to utilize skills similar to those employed in the current technology but to provide only a marginal improvement in functionality. While these situations may support some growth option value, the modest magnitude of this value indicates that the influence of any option value will be dominated by the traditional net present value of the current technology.

DISCUSSION

Motivated by the conflicting prescriptions of real option analysis with respect to growth and deferral option value, this chapter describes how expectations regarding future technological developments are likely to affect a firm's technology migration strategy. We consider the effect of the expected economic significance of future innovations, the frequency with which these future innovations arrive, the amount of inter-generational learning that can be transferred from an existing to a new technology, and the degree of uncertainty surrounding these innovations on the decisions to adopt current and future technologies.

The conceptual framework presented in this chapter contributes to the recent discussion regarding distinctions between growth and deferral options. Since the values of both options rise with uncertainty, and because the two options have opposing effects on the incentive to invest, the theoretical literature suggests that the effect of uncertainty is ambiguous (Abel, Dixit, Eberly, & Pindyck, 1996).

We submit that by jointly considering the duration of time until the next decision period, the degree of uncertainty regarding the comparative values of the future and current technologies, and the extent to which knowledge may spill over across technological generations, it is possible to assess the relative magnitude of growth and deferral option value. By illuminating the tradeoff between growth and deferral option value we hope to address a major issue that has limited the development of real option theory and its dissemination into practice.

In addition to addressing the real option literature, our work also contributes to the technology strategy and inter-generational learning literature. The introduction of real options analysis to studies of technology adoption provides a general theoretical framework with which to analyze the factors that influence whether and when firms should adopt a given technology. In so doing, we highlight two types of expectations that are likely to affect firms' current technology postures in the presence of expectations regarding future technologies – uncertainty and frequency of change. Finally, our model has implications for an ongoing debate in the economic literature that has shown that as the significance of the future technology increases, or becomes "drastic" in the sense used by Arrow (1962), the likelihood of adoption of the current technology may be mitigated (e.g., Arrow, 1962; Gilbert & Newberry, 1982; Reinganum, 1983). The model provides a conceptual explanation for analytical work that has shown that the "Arrow" effect depends on the degree to which innovation destroys existing market power and the uncertainty surrounding the timing of the introduction of the innovation (e.g., Gilbert & Newberry, 1984; Reinganum, 1984).

This paper also helps to clarify the role of inter-generational learning. While the notion of inter-generational learning spillovers is well established in the technology literature (Irwin & Klenow, 1994), its use as a measure of the strength of the preferential claim on subsequent generations of technology has received little attention. The mapping of inter-generational learning onto an option-based model of technology adoption allows an explicit comparison of the economic benefits provided by this learning vis-à-vis alternative investments. Backward induction reveals that the value of inter-generational spillover is directly tied to the attractiveness of the future technology. This value is a function of the expected economic significance of the future technology. Real option analysis, however, demonstrates that uncertainty in the value of the future technology and the duration of time until the arrival of the future technology provide an additional upside to the future technology value.

This paper is not without limitations. First, we ignore portfolio effects of real options. To the extent that there is unobserved heterogeneity across firms in their portfolio of sunk investments, some firms will be able to productively adopt technologies that other firms cannot without experiencing greater risk (e.g., Dixit & Pindyck, 1994; Trigeorgis, 1998). Moreover, firms' innovative capabilities are not explicitly considered. We also do not account for the effects of competitive interaction in adoption decisions.

Future research should address some of the limitations discussed above, as well as empirically test the arguments presented.

This exercise suggests a number of opportunities for management scholars to study the similarities and differences between stand-alone and dynamic approaches to new technology adoption. As the complexity and rapidity of technological change increases, these research directions will likely take on greater importance.

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BUSINESS METHOD PATENTS AS REAL OPTIONS: VALUE AND DISCLOSURE AS DRIVERS OF LITIGATION

Atul Nerkar, Srikanth Paruchuri and Mukti Khaire

ABSTRACT

This paper proposes that patents are real options that allow holders of patents the right but not the obligation to sue others. We suggest that the likelihood of a patent being litigated is positively associated with value of the patent and the extent of disclosure (prior art cited) in the patent. However, under conditions of greater value, increases in disclosure reduce the likelihood of litigation of the focal patent. Similarly, under conditions of greater disclosure, increases in value reduce the likelihood of litigation of the focal patent. Rare events logit analyses of business method patents that were litigated, compared to patents that were not litigated, offer empirical evidence supporting the hypotheses.

A patent is nothing but the right to sue

–CEO of an Intellectual Property licensing company

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Knowledge codified as intellectual property is considered a key asset that can deliver competitive advantage and superior performance for firms (Argote, McEvily, & Reagans, 2003; Cockburn, Henderson, & Stern, 2000; Spender, 1996). Considerable research exists on the drivers of research and development activities that lead to the creation and protection of such intellectual property (Helfat, 1994; Lanjouw & Schankerman, 1997). That said, this stream of research has typically considered patents as a means of protecting the intellectual property developed by a firm. While we do not take issue with the well-known fact that patents can provide barriers to entry, we incorporate a different but complementary view of patents in this paper; we consider patents to be real options that provide the right to sue other firms but not the obligation. More specifically, we argue that firms sue other firms as a way of exercising the real option represented in the patent granted to them. Our paper suggests that the likelihood of litigation of a patent is a function of the value of the patent as well as the extent of disclosure in the patent. Further, under conditions of greater value, the relation between disclosure and likelihood of litigation is negative as compared to conditions when the value is lower. Similarly, under conditions of greater disclosure, the relation between value and likelihood of litigation is negative as compared to conditions when the extent of disclosure is lower.

Past and recent research on real options has considered a whole host of decisions as real options – joint ventures (Cuypers & Martin, 2007; Kogut, 1991), R&D (Kumaraswamy, 1996; McGrath & Nerkar, 2004), project management (Huchzermeier & Loch, 2001), and venture capital investments (Guler, 2007; Hurry, Miller, & Bowman, 1992). In contrast, this paper contributes to the empirical research on real options by offering new insights into the factors that affect the likelihood of litigation by considering patents as real options (Reuer & Tong, 2007). These insights highlight the duality of the disclosure of information in the patent i.e. prior art cited in the patent can act as a building block of knowledge that allows other firms to imitate and infringe the patent as well as a fence that marks out the boundary of the intellectual property covered by the patent. Our findings are counter-intuitive, as they suggest that patent holders may be hoping for infringement of patents filed as real options in contrast to hoping for protection, which is expected when they are filed as isolating mechanisms. Further, potentially high value patents are more likely to have less prior art disclosed, compared to low value patents as the cost of citing a patent is non-trivial (Trajtenberg, 1990); under conditions of high value prior art is likely to act as a fence, while under conditions of low value prior art is likely to act as a building block. The remainder of the paper is developed as follows. We first make the argument for patents as real options. In the next section, we develop hypotheses relating the likelihood of litigation of patents with their underlying value and their infringement. In the third section, we describe our data collection procedures, analytical techniques, and results. We conclude with a discussion of the implications for research and practice.

THEORETICAL BACKGROUND

Patents as Real Options

Traditional forms of protecting knowledge include, but are not limited to, patents, trademarks, and trade secrets (Levin, Klevorick, Nelson, & Winter, 1987). The accepted economic reason for allowing patents on inventions and innovations is the 'reward or incentive' hypothesis. This notion suggests thatin the absence of patent protection, inventors would have little incentive to invest in innovative activity (Anton & Yao, 1994). Specifically, given that potential profits accruing from innovations would be rapidly reduced to the marginal cost of producing the innovations, it would not make any economic sense to invest in uncertain activities such as research and development. Also, because mechanisms such as trade secrets are less likely to protect the new knowledge generated, there would be a general tendency in society to be less innovative. Because of the monopoly rights that they grant to the innovator, patents are considered to help public welfare through the requirement of disclosure i.e. the requirement that a patent provide a complete description of the innovation. The implied assumption is that the inventor knows the usefulness and value of the patented innovation even though the underlying process by which such innovation emerges may be uncertain (Nelson & Winter, 1982).

However, the efficacy of patents in preventing imitation or market entry has varied across sectors. Levin et al. (1987) found that patents were effective isolating mechanisms in the pharmaceutical, chemical, and semiconductor industries. In many other industries, however, patenting did not provide any competitive advantage to the holder or assignee of the patent. That said, there has been an upsurge in patenting in the 1990s across all sectors including pharmaceuticals, chemicals, and electronics (Kortum & Lerner, 1999). While this upsurge can be partly explained by the huge changes in technology and R&D, other explanations such as changes in the patenting law itself as well or the motivations of the assignees of the patents are also plausible.

The debate of the efficacy of patents as a method to increase innovative productivity is beyond the scope of this paper.[1] However, it is important to highlight one empirical fact, which has been pointed out by researchers studying R&D, technological change, and patents that majority of the patents granted by patent offices across the world are worthless (Pakes, 1986). This then begets the question why do firms file for patents? The answer lies in a complementary view of patents as real options. According to Kitch (1977), one of the first researchers to formally state this complementary view:

> The importance of the prospect function in the American patent system is argued from three features of the system. The first is the scope accorded to the patent claims, a scope that reaches well beyond what the reward function would require. Second, there are rules, such as priority, time-bar, and patentability rules, which force an early patent application whether or not something of value (and hence a reward) has been found. And third, there is the fact that many technologically important patents have been issued long ago before commercial exploitation became possible.

If patents are prospects, firms need to explore these prospects to generate revenue. There are three lines of action before a patent holder. First are the rights but not the obligation to leverage a patented invention into a commercial product. Second are the rights but not obligation to license the invention to other firms by using the patent to resolve the 'trading in knowledge' problem (Arrow, 1962). Both the rights of licensing and leverage are helped by a third line of action available to a patent holder i.e. the right to sue (litigate against) any party that infringes the patent and seek damages and/or royalties. This right, though primarily an enforcement mechanism for the other two rights (leverage and licensing), has in itself become a line of action in the pursuit of profit. Other researchers studying patents through the options lens as well as other theoretical approaches have focused on the right to license and leverage the technology underlying the patent (Shane, 2002; Ziedonis, 2003a), while scholars in legal studies and economics have studied the determinants of patent litigation without invoking a real options framework (Lanjouw & Schankerman, 2001). In contrast, this paper focuses on the right to litigate that is offered by a patent through a real options framework.

There are issues with testing this complementary view of patents as a prospect system that allows the grant of real options. A real option as defined in the literature is the right but not an obligation bought for a small investment (also known as option price) on the part of a firm or entity to continue or not continue with a set of activities in the future (Mitchell & Hamilton, 1988). Any real option decision has four features to it: a relatively small investment, uncertainty with respect to the course of future action associated with the patent, boundedly rational decision makers, and a time frame in which the decision has to be made. A patent is analogous to a real option as it allows the firm that files the patent the right to license, litigate, or leverage the patent for a small investment (filing fee along with attorney fees) compared to the costs of subsequent litigation, licensing, or leverage.[2] Further, the carrying costs of this option are presumably small or trivial compared to the gains from exercising the right to sue. There is uncertainty with respect to the course of action to be followed and finally patent validity is limited to 20 years.

Scholars have criticized research in the real options area as not having shown evidence ruling out alternative explanations (Adner & Levinthal, 2004; Coff & Laverty, 2001; Garud, Kumaraswamy, & Nayyar, 1998). More specifically, for a decision to have a real options explanation, researchers should be able to demonstrate the opening of the option as well as its exercise. Further, the exercise of the option has to be connected with the value of the asset covered by the option. Research on patents as options in general alleviates the first criticism by examining the exercise of the right to sue conferred by a patent. However, the right to sue is not exercised with the intention to profit in some sectors, especially those that involve systemic technologies such as semiconductors, as the patent instead of being an option on methods of increasing profits acts as a defensive mechanism to protect existing profits. Further, in these sectors the right to sue is also a function of a host of other factors other than the value of the option. For instance, the large pharmaceutical companies are more likely to sue or get sued since they maintain huge legal departments. While these firms may adopt real options reasoning in their investments, it is difficult to separate the 'prospective profit' motive from defensive intentions of patenting (McGrath & Nerkar, 2004). We handle these issues by choosing a sector, business method patents (described in greater detail in the methods section), which represents a level playing field with respect to all firms irrespective of sector or size. By level playing field we mean that investments in the underlying technology of business method patents in the form of physical plant, equipment, and/or personnel are not huge as in the case of research and development in areas like pharmaceuticals and chemicals.

Given a situation, where firms file patents as options with expectations of profit through litigation, which patents do get litigated and why?

HYPOTHESES DEVELOPMENT

Considerable research exists on the enforcement of property rights, both real and intellectual. We draw from this theory to develop specific hypotheses linking patent attributes to likelihood of litigation. The rights to intellectual property are protected in two ways: by court orders that stop infringement and by holding the infringer liable to damages (Schankerman & Scotchmer, 2001). The damages are decided on the basis of lost profits of the patent holder and unjust enrichment enjoyed by the infringer. In the context of patents, a necessary condition for filing a suit is the *belief* that the property rights of the patent holder have been violated or infringed upon by another firm or entity (Cooter & Rubinfield, 1989). In the absence of this belief a suit will not be entertained in any court. Given that a patent has been filed explicitly with the intention to explore the right to sue, a firm looking to gain from such litigation is more likely to enforce patents through litigation if they have been infringed.

However, research on litigation shows that in many cases firms file law suits (in spite of clear lack of evidence) where the issue at stake is of considerable value. Such litigation has also been called 'bounty hunting' (Besaha, 2003). The intention is to try for settlement without taking the suit to adjudication. In the case of computer software, submarine patenting is often resorted to in order to harvest the benefits of such litigation. For instance, Unisys filed a suit for infringement against Compuserve after obtaining a patent on an algorithm that formed the basis of the graphics interchange format (GIF) protocol (Lerner & Conway, 1996). GIF had become a de facto standard in the computer graphics area because of its 'public' nature at the time of its initial development. This did not prevent Unisys from filing suits of infringement against users. The value resulting from such settlements is an important reason for exercising the option to sue independent of whether the patent has been infringed.

Financial options theorists have used the Black-Scholes model for valuing financial options (Black & Scholes, 1973). However, the application of this model for valuing real options is impractical as the estimates for the various parameters involved in the Black-Scholes formula are at best assumptions (Black, 1992). However, one can use the logic behind the Black-Scholes formula to understand the reasons for litigation. According to this model, an option will be exercised when the option is 'in money' i.e. the benefits from exercising the option are greater than holding it. Researchers studying real options are unequivocal about the factors that drive option value (Pitkethly, 1997). The four factors that are considered key to option value as per the Black-Scholes formula are the stock price (value of the knowledge contained in the patent), exercise price (preliminary filing costs for legal action to sue), time to expiration of the patent, and volatility of the returns (Black & Scholes, 1973). A patent is valid for 20 years from filing date after it has been granted, while the cost of filing a suit would be similar across patents in a technical area (as in business method patents).[3] Finally, the volatility of the returns would be similar for patents in the same technical area. After controlling for the technical area in which a patent is granted, the decision to sue is dependent on the value of the option, which in itself is dependent on the stock price or the value of the patent.

The two factors – infringement and the value of the intellectual property covered in the patent – are therefore independently and jointly associated with the likelihood of litigating a patent.

INFRINGEMENT, DISCLOSURE, AND LIKELIHOOD OF LITIGATION

The cost of obtaining the patent is miniscule compared to the cost of starting and continuing the litigation (Llobet, 2003). A patent holder needs to decide whether or not to exercise the right to sue other firms for damages and/or royalty payments. Patents grant a temporary monopoly (right of excluding others from using, selling, or in any other way distributing the ideas covered by the patent) to the owner. The price of this protection is disclosure about the invention by the inventors. The monopoly provides the inventor with the incentive to make the invention public, while the disclosure helps spur innovation by other inventors who can now use the patented knowledge in subsequent work (Scotchmer & Green, 1990). The disclosure of the invention is thus a double-edged sword. The formal objective of the patent system is to increase innovative productivity while providing property rights to the patent holder. However, the nature of the disclosure in the patent can lead (as described later) to imitation, reengineering, and consequently infringement.

Disclosure of a patent typically contains details of the inventive process as well as the references or knowledge on which the inventive process is based. The nature and disclosure of prior art can lead to infringement of the intellectual property covered by the patent in three ways and consequent exercise of the option to sue. First, prior art provides a link to the building blocks of the innovation that have been recombined. R&D processes are recombinant in nature, and by examining the prior art provided in the focal patent, other firms can imitate the invention by recombining the same prior art (Fleming, 2001). This may lead to infringement and decision by the firm holding the patent to sue. Second, the presence of prior art is also an indicator of other firms that are active in the area covered by the focal patent.

Technological crowding is likely to lead to infringement and exercising the right to litigation. Third, prior art that is public knowledge and is well established is more likely to be part of the building blocks of other patents leading to increases in infringement. This infringement may happen knowingly as well as unknowingly.

However, the disclosure of prior art in the patent can also decrease infringement or the possibility of infringement. Firms active in the area covered by the patent may decide to be careful in their activities, as they understand the boundaries of the patent. If the prior art cited in the patent is well known or old, it is possible that competing firms may respect the boundaries of the property as they believe that the recombination effort is something that is novel and non-obvious. The above reasoning is best explained by comparing a patent to a piece of real estate. To the extent the real estate is surrounded by other occupied pieces of real estate or connected to other public properties, the owner will have to fight encroachment efforts by exercising right of litigation embedded in the patent. However, if the boundaries of the real estate are clearly defined and fenced, such encroachment efforts and litigation are less likely. Prior art disclosure in a patent thus serves two roles: (1) as a building block and (2) as a fence that defines the intellectual property covered in the patent. The greater the number of building blocks available to competition, the more likely it is that infringement of the patent and consequently the right to litigation will be exercised. In contrast, the more clearly demarcated the fences that surround the patent are, the less likely it is that infringement and litigation will take place. Thus we hypothesize:

H1a. The greater the disclosure in the patent, lower the likelihood that the right to litigate provided by the patent will be exercised.

H1b. The greater the disclosure in the patent, greater the likelihood that the right to litigate provided by the patent will be exercised.

VALUE AND LIKELIHOOD OF LITIGATION

Patents are filed at a time when firms are unsure about their commercial value. Past research shows that most patents are worthless in terms of their commercial value but the few that are valuable make it worthwhile to file the others. The options logic underlying the filing of patents suggests that firms are likely to exercise their right to sue other firms when they believe that the potential benefits accruing from litigation far outweigh the costs of litigation that in turn is largely a function of the value of the patent. The value of the intellectual property is determined by what the patent covers and the extent to which it is relevant to the rest of the world.

To continue with the analogy from real estate, while prior art defines the fences of the property, the claims define what is within the fences of the property. The claims are a map of the property whereas citations represent the number of times people have walked on the property. The more claims a patent makes, the greater is the delineation of the intellectual property covered by the patent (Tong & Frame, 1994). In contrast, the citations that a patent receives determine its actual relevance to the rest of the world. The greater the number of citations, the more useful the technology covered by the patent is to the rest of the world (Albert, Avery, Narin, & Mcallister, 1991). A firm that holds a patent may decide to sue firms that are citing its work even though such citations may not represent infringement. The intention would be to obtain a licensing contract in its favor (Anand & Khanna, 2000). Greater claims in a particular area will help a firm to identify potential infringers or licensees even though such infringement may not have necessarily taken place. For instance, Jerome H. Lemelson, one of the most prolific independent inventors of the 20th century frequently filed patents in technological areas (not necessarily business method areas) where the likelihood of litigation leading to licensing fees and damages was much higher (Baker & Ertel, 2002)

H2. The greater the value of a patent as seen in its claims and citations subsequent to grant, greater the likelihood that the right to litigate provided by the patent will be exercised.

INTERACTION BETWEEN VALUE AND DISCLOSURE

Our arguments so far have hypothesized a direct association between disclosure, value, and the likelihood of exercising the right to litigate. Further, the association between disclosure and the likelihood of litigation can be either positive or negative. In this section we try to resolve this duality by examining the interaction effects between the above constructs. Under conditions of high value, increases in disclosure in a patent will lead to such disclosure acting as a fence. Competitors will be careful about using the knowledge disclosed in it, as the cost of such infringement may far exceed the potential benefits that would accrue from such imitation. Also, the more established the knowledge cited in the disclosure, the greater the understanding of this knowledge by other firms and hence, the lower is the likelihood that they will encroach on the intellectual property covered by the patent. Finally, increases in disclosure in the presence of value may help a court to decide in favor of the patent holder. In contrast, under conditions of low value, competitors are less likely to be worried about damages resulting from any infringement and may use the disclosure as a building block to imitate or reengineer the technology covered by the patent leading to increases in infringement and consequently in the likelihood of litigation.

Similarly, the relation between value and likelihood of litigation will be moderated by the extent of disclosure in the patent. However, the disclosure in this case acts as a fence and not as a building block. In a situation where disclosure is minimal, other firms are more likely to imitate or reengineer the patent with increases in value, thus causing patent holders to litigate to recover damages and/or royalties. In contrast, with greater disclosure, competitors are less likely to cross the fence with increase in value and hence the likelihood of litigation is lowered.

H3. The value of a patent and extent of disclosure of knowledge in the patent will interact with each other in their relationship with likelihood of litigation i.e.

- Under conditions of high value (disclosure), increases in disclosure (value) will lead to decreased likelihood of litigation.
- Under conditions of low value (disclosure), increases in disclosure (value) will lead to increased likelihood of litigation.

DATA

Our theory suggests that patents are real options, which confer the right but not the obligation to sue others who have infringed or are likely to infringe the patent (Bloom & Van Reenen, 2002). Each patent contains extensive information about the inventor, the company to which the patent is assigned, and the technological antecedents of the invention in the form of other patents that it cites. The above information can be accessed in computerized form. Every patent is assigned to a three-digit technical class, which we use for the purpose of identifying distinct technical areas being developed by the firms in our sample. At this level, there are currently 400 such technical three-digit classes. We follow other researchers who have used information on the front page of the patent relating to technological classes, subclasses, assignee names, grant dates, application dates, and the geographical locations of inventors and patents cited while studying corporate entrepreneurship, technology licensing, and related issues (Ahuja & Lampert, 2001; Almeida & Kogut, 1999; Henderson & Cockburn, 1996). The issuance of a patent to a firm provides archival evidence of the grant of a real option (Pakes, 1986).

Choosing a random sample of patents as has been done by other researchers studying patent litigation (Lanjouw & Schankerman, 2001) or focusing on technological sectors where patenting has been prolific and useful, such as pharmaceuticals, may make it difficult to disentangle whether such litigation is a result of defensive efforts versus litigation as a result of 'prospecting' efforts or real options logic. To overcome this problem, we focus on a new class of patents on 'business methods'. In 1998, the United States patent system underwent a change whereby patents on 'ideas' or business methods that were non-obvious, non-trivial, and of some value were granted (Keeley-Domokos, 1999). Prior to this 'State Street Decision' as it is now known, patents could not be granted purely for ideas; the invention had to manifest itself in a physical prototype or architecture.[4] As a result, a large number of companies involved in commerce on the Internet (e-commerce) filed for patents in this area (Allison & Tiller, 2003). Recent anecdotal evidence suggests that these companies intended to use these patents as profit-generating mechanisms by suing other firms (Caruso, 1999).

A second reason for focusing on business method patents is that it allows us to test for the direct effect of the characteristics of the patent on the likelihood of litigation without considering factors such as industry structure and competition that are very important in other sectors (Kamien & Schwartz, 1974). More specifically, patents in the chemical and pharmaceutical sectors are the result of many years of sustained R&D in the presence of essential expensive complementary assets such as R&D laboratories and well-trained scientific personnel (Arora, 1995; Teece, 1986). Patents in the semiconductor sector are primarily used as a defensive mechanism i.e. to prevent other companies from entering the area and the likelihood of litigation in such sectors is as much a function of the industry structure as it is with the value associated with a patent (Ziedonis, 2003b). In contrast, business method patents are the result of predominantly mental activity on the part of the inventor without the use of expensive complementary assets. The costs of developing an idea that will lead to the filing and subsequent grant of a business method patent are correspondingly lower than those associated with physically intensive sectors, such as chemicals, pharmaceuticals, and semiconductors (Merges, 1999). This is also evidenced by the fact that a substantial percentage of the business method patents have been granted to independent inventors and companies that are small and privately held

(Allison & Tiller, 2003). Thus, the cost and time required for generating intellectual property in this area are relatively less and in some sense the market for business method patents mimics a situation where size does not matter and all firms are created equal.

To test our hypotheses, we collected all business method patents (US patent class 705) granted between 1971 and 2000. The unit and level of analysis are the individual patents and their associated content. We consider only patents filed in the United States. The sources for this information include the US Patent Office and online databases. We first identified the entire lot of business method patents from the US Patent Office for the last 30 years numbering 4071. These 4071 patents were then compared with Lexis-Nexis records to identify those patents that were litigated. On the basis of this comparison, we identified the 76 patents that were litigated by patent holders for infringement.[5] These patents were litigated by distinct companies and did not include any countersuits filed by the infringers.

MEASUREMENT

Dependent Variable

The dependent *status* variable is a categorical variable and is coded as 1 if the patent was litigated as infringed upon by the patent holder and 0 if the patent was not litigated till the end of year 2002.

Independent Variables

The main independent variables in the model are operationalized as follows:

Disclosure

An ideal approach for understanding the extent of disclosure would be to read each and every patent and develop a measure of disclosure based on this analysis. However, given huge numbers of patents in the area and the technical expertise required we chose to measure disclosure in three ways: patented prior art, academic prior art, and age of patented prior art, respectively. *Patented prior art* is the number of patent references in the focal patent, while *academic prior art* is the number of non-patent references in the patent (Fleming & Sorenson, 2004). The *age* of the patented prior art is measured as the average age of the patent references i.e. difference between grant date of the focal patent and each patent reference (Nerkar, 2003). We use age as a proxy for disclosure as older knowledge would have had more time to be disseminated or flow in contrast to new knowledge. Each of these indicators provides information about the origins of the invention covered in the patent.

Value of a Patent

The two measures of value that we used are the number of *claims* in a patent and the number of *citations per year* since time of grant.[6] This is consistent with past research that has found strong empirical evidence supporting the link between value and citations received and claims (Albert et al., 1991; Tong & Frame, 1994).

Control Variables

We use four control variables that control for other characteristics associated with a patent. *Patenting experience* is measured as the number of business method patents that a firm was granted before the patent under consideration was litigated. By including this variable we control for the possibility that a patent may or may not be litigated because the experience a firm possesses in the area. *Scope* of the patent beyond business methods is measured as the number of technological classes that a focal patent is classified in other than '705,' which is the business methods class (Lerner, 1995). By including this measure, we take into account the possibility that broad-scope patents, which have technological applications beyond business methods, are more likely to be litigated. Third, we include a control, *time to grant*, which measures the time the patent took to be approved by the patent office. This control takes into account the fact that complex patents may take more time to grant and are also more likely to be litigated. Finally, we include, *inventor locations*, a variable that measures the number of distinct geographic inventor locations (cities) represented on the patent. By including this variable we hope to control for the geographical diversity and its influence on the likelihood of litigation of a patent (Almeida & Kogut, 1999).

ANALYTICAL TECHNIQUE

Numerous statistical models such as discriminant analysis, probit analysis, and logit analysis exist for the classification of dichotomous data.[7] Logit analysis is the main technique used in this paper. While discriminant analysis, a popular technique in classifying dichotomous outcomes, generally performs well in classification accuracy, it assumes that the independent variables are multivariate normal and that the covariance matrices of the two groups are equivalent. To avoid the restrictive assumptions of discriminant analysis, we use logit analysis since it is a conditional probability model that uses maximum likelihood estimation. It has the objective of providing the conditional probability of an observation belonging to a certain group, given the values of the independent variables for that observation. Logit analysis is based on cumulative probability function and does not require that the independent variables be multivariate normal or that the groups have equal covariance matrices ensuring that we do not have to transform any of our independent variables.

Two approaches have been used in past research to conduct logit analysis. The first approach uses the entire lot of business method patents, while the second adopts a 'case-control' or matched sample approach. We cannot use either of these approaches in our analyses, as business method patents litigations are rare (76) compared to the number of patents granted in the area (4071) due to which our parameter estimates would be biased.

Fig. 1 shows the number of business method patents granted is far more than those that get litigated. Rare events underestimate the probability of an

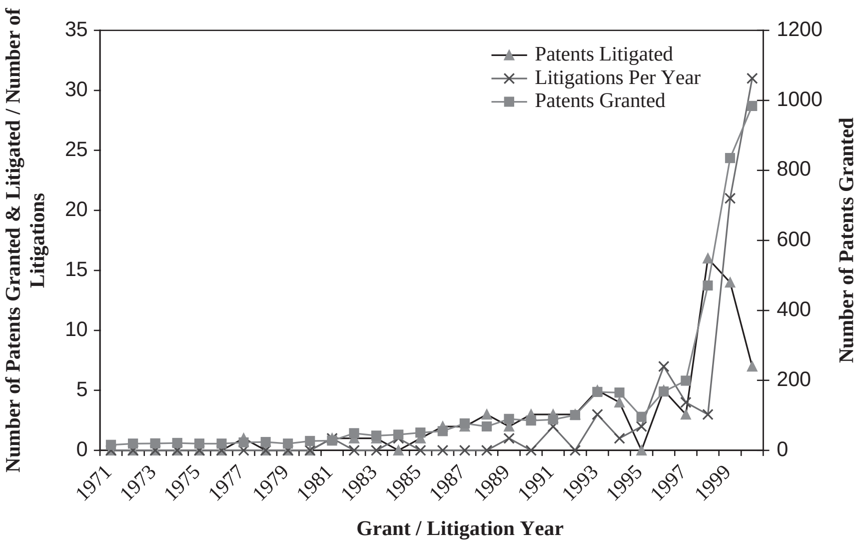

Fig. 1. Litigation and Business Method Patenting.

event and do increasingly as the event becomes rarer. We follow Sorenson and Stuart (2001) who adopt a methodology to generate unbiased estimates under such conditions of "rare events.[8]" Under this methodology, a correction is applied by using weighting mechanism for the estimation that accounts for oversampling of the "rare" events (King & Zeng, 2001). This procedure entails two things. First, a sample of all "events" and a fraction of non-events are selected. In this particular case, we select those patents that are litigated and a fraction of patents that are not litigated. This sample of nonevents is selected randomly. Next, a method is applied that corrects the bias and generates consistent estimates. We use the statistical analysis program 'Stata' that has a correction procedure called 'relogit' (Tomsz, 1999).

RESULTS

The correlations and descriptive statistics are presented in Table 1. None of the bivariate correlations are above 0.40, alleviating concerns of multicollinearity. Results of multivariate analysis are presented in Table 2. Model I consists of only control variables and none of these are significant. Model II presents control variables along with the value variables, citations per year and claims, both of which have a positive and significant effect on litigation. That is, the more the value of the patent, the more the probability that it will be litigated. Further, the citations per year have a higher effect on the likelihood of litigation than do claims. Models III through V introduce each of the disclosure variables into the analysis. All three disclosure variables – academic prior art, patented prior art, and age of prior art – have a positive and significant effect on probability of litigation, suggesting that disclosure in the form of prior art acts as a building block of knowledge as opposed to a fence. The full model is presented in Model VI. The coefficients are positive but the significance of the disclosure variables is reduced i.e. only age of prior art is significant. We also computed the relative strengths of each of the variables on the likelihood of litigation. Based on Model VI keeping all variables at their mean level, we computed the increase in log likelihood of litigation with an increase of 1 unit in citations per year, claims, and average of patented prior art. We find that a 1-unit increase in citations per year, claims, and average age of patented prior art leads to a 45, 4.35, and 12.5% increase in log likelihood of litigation. Citations per year lead to the most significant increase in log likelihood of litigation.

Table 3 presents results of rare events logistic models that include interaction terms. Models VII through X consist of interaction terms of citations

Table 1. Statistics and Correlation Matrix (All Business Method Patents).

	Variable Description	Mean	SD	Min.	Max.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1)	Status (litigated = 1, not litigated = 0)	0.02	0.14	0	1	1.000								
(2)	Citations per year	1.87	2.36	0	32.43	0.127	1.000							
(3)	Claims	21.13	20.08	1	375	0.044	0.162	1.000						
(4)	Academic prior art	10.61	50.05	0	784	−0.005	0.080	0.120	1.000					
(5)	Patented prior art	12.77	16.60	0	266	0.000	0.138	0.223	0.349	1.000				
(6)	Age of prior art	6.66	4.03	0	75.90	0.006	−0.038	−0.002	0.032	0.205	1.000			
(7)	Inventor locations	2.32	1.77	1	15	−0.009	0.046	0.097	0.028	0.044	−0.049	1.000		
(8)	Time to grant	2.55	0.98	0	11.04	0.002	0.007	0.072	0.060	0.036	0.140	0.057	1.000	
(9)	Scope	2.31	1.15	1	10	0.000	0.013	−0.048	−0.035	0.022	0.069	−0.027	−0.083	1.000
(10)	Patenting experience	19.31	46.53	0	289	−0.013	−0.125	−0.071	−0.031	−0.004	−0.017	0.084	0.036	−0.040

Note: All correlation coefficients above |0.1| are significant at $p < 0.05$.

Table 2. Rare Events Logit Model Predicting Likelihood of Litigation[a].

Variable Description	I	II	III	IV	V	VI
Citations per year		0.2469***				0.3768***
		(0.0901)				(0.1020)
Claims		0.0426***				0.0273**
		(0.0126)				(0.0115)
Academic prior art			0.0262**			−0.0046
			(0.0123)			(0.0128)
Patented prior art				0.0448**		−0.0135
				(0.0209)		(0.0114)
Age of patented prior art					0.1051**	0.1180**
					(0.0502)	(0.0544)
Inventor locations	−0.0751	−0.0762	0.0081	−0.0837	−0.0204	−0.1010
	(0.0981)	(0.1325)	(0.0795)	(0.0764)	(0.0968)	(0.1287)
Time to grant	−0.0826	−0.0192	−0.0598	−0.0090	−0.0492	0.0064
	(0.1644)	(0.1198)	(0.1597)	(0.1608)	(0.1584)	(0.1762)
Scope	0.0558	−0.0115	0.0586	0.0459	0.0630	0.0395
	(0.1262)	(0.1547)	(0.1319)	(0.1365)	(0.1381)	(0.1581)
Patenting experience	0.0004	−0.0006	−0.0007	−0.0009	−0.0011	0.0020
	(0.0036)	(0.0033)	(0.0037)	(0.0037)	(0.0039)	(0.0035)
Constant	−3.6224***	−5.1998***	−4.0475***	−4.2439***	−4.5019***	−5.9268***
	(0.5394)	(0.6348)	(0.5810)	(0.5960)	(0.6103)	(0.6414)
LL	−125.4115	−99.4761	−119.8964	−118.4125	−116.9104	−101.4657
Improvement		25.9354***	5.5150**	6.9989**	8.5010	23.9458***
Comparison model		I	I	I	I	I

**$p < 0.05$ (two-tailed tests).
***$p < 0.01$ (two-tailed tests).
[a]Number of patents litigated for infringement was 76. Values in parentheses are robust standard errors.

Table 3. Rare Events Logit Model Predicting Likelihood of Litigation.

Variable Description	VII	VIII	IX	X	XI	XII	XIII	XIV
Interaction effects								
Citations per year	0.4392***	0.4693***	0.7372***	0.7221***	0.3905***	0.3451***	0.3019*	0.1779**
	(0.1094)	(0.1338)	(0.2332)	(0.1899)	(0.0881)	(0.0847)	(0.1681)	(0.0758)
Claims	0.0236**	0.0329**	0.0249*	0.0368***	0.0191*	0.0686***	0.0381**	0.0124
	(0.0119)	(0.0128)	(0.0133)	(0.0133)	(0.0117)	(0.0204)	(0.0189)	(0.0298)
Academic prior art	0.0426*	0.0059*	0.0025	0.0817***	0.0846***	0.0091	−0.0035	0.0327**
	(0.0237)	(0.0034)	(0.0099)	(0.0248)	(0.0292)	(0.0180)	(0.0078)	(0.0144)
Patented prior art	−0.0041	0.0215	−0.0162	−0.0304	−0.0150	0.1052***	−0.0127	0.0214
	(0.0120)	(0.0167)	(0.0134)	(0.0277)	(0.0146)	(0.0436)	(0.0108)	(0.0338)
Age of patented prior art	0.0099	0.0101	0.2022***	0.0489	0.0211	0.0281	0.2593***	−0.0678
	(0.0536)	(0.0423)	(0.0762)	(0.0373)	(0.0430)	(0.0306)	(0.0977)	(0.0780)
Citations × academic prior art	−0.0120**			−0.0161***				
	(0.0047)			(0.0050)				
Citations × patented		−0.0117**		−0.0067				
		(0.0055)		(0.0063)				
Citations × age			−0.0494**	−0.0079				
			(0.0220)	(0.0186)				

Claims × academic prior art					−0.0012***			−0.0016**
					(0.0004)			(0.0007)
Claims × patented prior art						−0.0025**		−0.0007
						(0.0013)		(0.0009)
Claims × age of patented prior art							−0.0041*	0.0053
							(0.0022)	(0.0041)
Inventor locations	−0.0813	0.0317	−0.0142	0.0090	−0.1258	−0.1571	−0.1151	−0.1390
	(0.1245)	(0.1039)	(0.1048)	(0.1127)	(0.1045)	(0.1073)	(0.0898)	(0.0887)
Time to grant	−0.2170	−0.1307	−0.1180	−0.3972	−0.1361	−0.2203	−0.0622	−0.0601
	(0.1460)	(0.1384)	(0.1342)	(0.1894)	(0.1545)	(0.1470)	(0.1510)	(0.1615)
Scope	−0.1727	−0.1484	−0.1911	0.0174	−0.0589	0.1188	−0.1333	0.0068
	(0.1475)	(0.1535)	(0.1542)	(0.1588)	(0.1420)	(0.1728)	(0.1476)	(0.1345)
Patenting experience	0.0038	0.0020	0.0040	0.0058	0.0012	−0.0007	0.0060	0.0004
	(0.0042)	(0.0033)	(0.0036)	(0.0045)	(0.0038)	(0.0039)	(0.0038)	(0.0031)
Constant	−4.4961***	−5.1637***	−5.8975***	−5.3522***	−4.7472***	−6.2366***	−5.6843***	−4.4826***
	(0.6505)	(0.6748)	(0.7400)	(0.7891)	(0.7347)	(0.8158)	(0.8006)	(0.8256)
LL	−94.3608	−93.5253	−99.9226	−87.5634	−98.6129	−92.2304	−98.2913	−95.6733
Improvement	7.1048**	7.9403**	1.5431*	13.9023***	2.8527*	9.2352***	3.1743	5.7923**
Comparison model	VI	VI	VI	VI	VI	VI	VI	VI

Note: Values in parentheses are robust standard errors.
*$p<0.1$ (two-tailed tests).
**$p<0.05$ (two-tailed tests).
***$p<0.01$ (two-tailed tests).

per year with each of the disclosure variables. In Model VII, the interaction of citations per year with academic prior art is negative and significant, indicating that the effect of academic prior art on the probability of litigation is negatively moderated by the value, citations per year. The inflection point at which the relation changes between likelihood of litigation and academic prior art changes from positive to negative is 3.55 citations. Model VIII presents the parameter estimates of the interaction of citations per year with patented prior art, which is negative. The inflection point at which the relation between likelihood of litigation and patented prior art changes sign from positive to negative is 1.83 citations. The same effect holds for the age of patented prior art as shown in Model IX and the inflection point is 4.09 citations.

The inflection points at which the number of claims causes the relation between the disclosure variables and likelihood of litigation were computed and are 71, 42, and 63 for academic prior art, patented prior art, and age of patented prior art as seen from Models XI, XII, and XIII, respectively. The corresponding inflection points for patented prior art, academic prior art, and age of prior art where the association between value (citations and claims) and likelihood of litigation changes from positive to negative are 37, 2, 4 and 9, 42, and 36, respectively. All these inflection points are within the range of the data. When all these interaction terms are included in one model, Models X and XIV, only the interaction of value (claims and citations per year) with academic knowledge remains significant.[9] All the inflection points are within the range of the data.

DISCUSSION

The results presented earlier support most of our hypotheses. We had hypothesized a bidirectional relation between disclosure and likelihood of litigation. Our results suggest that prior art and age of patented prior art act as building blocks of knowledge rather than as fences. But with the introduction of increased value, these building blocks become signposts that define the technology and act as fences. While we cannot see evidence of actual infringement, the act of litigation with increase in disclosure is consistent with our theorizing. In particular, our results are largely consistent with the results of Lerner (1995) and Lanjouw and Schankerman (2001) and go beyond them by examining the interaction between knowledge on which a patent is built (disclosed) and the value seen in it. However, Model VI offers some non-results that need further explanation. While all our hypotheses are supported in the individual models, the full model supports the hypothesis associating value (both citations per year and claims) and disclosure (only age of patented prior art) with likelihood of litigation. We believe that this is because firms looking to exercise the right to sue are more likely to consider signals of value than signals of potential infringement. Schankerman and Scotchmer (2001) point out that there are two liability doctrines, lost profits and unjust enrichment, which determine damages in patent litigation suits. A patent of negligible commercial value that is litigated purely on the basis that it has been infringed will lead to a patent holder's gaining only 'lost profits'. In contrast, signals of value suggest that a patent holder could gain from the 'unjust enrichment' aspect of damages by settling before adjudication in case of lack of clear evidence of infringement or by gaining substantial damages resulting from both 'lost profits' and 'unjust enrichment' awarded at the time of adjudication in case of clear infringement. The age of the patented prior art continues to be positive and significant, suggesting that patents based on established knowledge are more likely to be infringed and litigated even in the presence of indicators of value.

Our results, while largely consistent with Lanjouw and Schankerman's (2001) findings, have one important difference. We find that prior art disclosed in the patent has a positive effect on likelihood of litigation that disappears only in the presence of signals of value. This – and the finding that in the presence of value, prior art disclosed, instead of providing building blocks of knowledge that can lead to infringement, becomes a fence that prevents infringement and consequently litigation – suggests that the drivers of business method patent litigation are more subtle and nuanced than those in other sectors. The marginal effects of citations and claims are far stronger in the context of business method patents than in the sectors reported by Lanjouw and Schankerman (2001). This offers strong support for our rationale that business method patents are real options that firms take out under situations of uncertainty with the intention of exploring the upside through litigation while limiting the downside.

Our results have important implications for different areas of research in strategic management. Barney (1986) states that any competitive advantages that can be obtained by getting resources in the strategic factor market will be competed away and consequently luck plays an important role in the acquisition, retention, and application of resources that provide superior performance. Our results suggest an alternative explanation to luck to the acquisition of such resources in factor markets such as markets for business method patents. These markets are as close to being perfectly competitive as compared to other sectors. Participants adopt a real options approach whereby they spend small amounts of money that provides them the right to prospect certain actions. A real options perspective allows firms to retain decision-making rights with respect to resources even though the process underlying the development of such resources is stochastic, uncertain or, in other words, driven by luck. A second application of our finding is related to the criticism of the resource-based view of the firm in recent times as tautological (Bromiley & Fleming, 2002; Porter, 1991; Priem & Butler, 2001). Our findings suggest that the common problem of conflating value and performance in the RBV can be resolved by allowing value to vary on a continuum. Similarly, the requirements of inimitability and substitutability, which are normally considered to be essential for competitive advantage to be derived from resources, are not essential in the case of business method patents when considered as real options that provide the right to sue. Finally, our paper offers a response to the comments and suggestions made by scholars on how real options logic should be researched (Adner & Levinthal, 2004; Li, James, Madhavan, & Mahoney, 2007). Our findings show that patents can be considered as real options and the grant of business method patents and their litigation is consistent with such logic.

The study suffers from limitations on a few fronts that help in identifying areas where future research could be conducted. Methodologically, the research would benefit from examining patents in all areas and comparing the results to the business methods area. Also, we focus on infringement actions while ignoring challenges. This level of detail was considered sufficient for the purposes of the present study. However, greater rigor can be introduced in a later research by examining the differences in likelihood of litigation across sources of legal action i.e. a patent holder or a competitor. From a conceptual angle, what may be of greater interest would be the settlement of these legal actions. It may be easier to start litigation but may be more difficult to sustain it. Future research could examine whether the results of this study extend to settlement of legal actions (Shavell, 1989; Somaya, 2003). While the focus of this paper has been on the right to sue, firms do have other lines of action such as licensing and leveraging technology into their own products. Future research should look at the link between these different choices and the manner in which firms makes decisions with respect to choosing one over the other.

There are other ways in which this research can be extended in the context of strategy and entrepreneurship research. The enforcement of intellectual property has been a topic much studied by economists from a welfare and public policy perspective. Management researchers have recently begun exploring the strategic implications of these and related issues. Our research contributes to this small but increasingly important stream of research. For instance, Somaya (2003) finds that settlement outcomes in patent litigation are a function of the strategy adopted by the patent holder, while Ziedonis (2004) shows that firms patent more aggressively than otherwise expected when markets for technology are highly fragmented. We have used citations to indicate value but some citations are more valuable than others. Also, the dispersion of these citations matters (Chi & Levitas, 2007). For instance, is a firm more likely to sue based on who cites it? Some business method patents can also be connected to systemic aspects of technology. Research suggests that such technologies have more partners and strategic alliances involved in their development (Chesbrough & Teece, 1996). Such partnerships and alliances may lead to a dampening of exercising the right to litigate. Future research could extend the findings of this paper by examining these effects. Challenges and reexaminations of patents need to be included in any future extensions. Finally, settlements and adjudications of these suits would be an important topic that could shed light on whether such options logic does lead to systematic sustained rents for patent holders. Our approach has been to consider litigations as the exercise of the option but one can also consider such decisions to be part of multistage options.

CONCLUSIONS

This study examines a relatively new patenting phenomenon, namely that of business method patents, and more specifically, the litigation activity within this patent class. The huge upsurge in business method patents can be explained by the 'prospective nature' of the patenting done in the area. Recent research has shown that business method patents are not deficient in terms of the prior art that they build on thus ruling out the lacunae in the patenting that allowed such patents to be granted (Allison & Tiller, 2003). Also, more of these patents have been granted to small and independent inventors compared to patents in other sectors, suggesting that these inventors are indeed looking at these patents as real options. Our findings extend previous research on patent litigations by exploring how the nature and strength of the knowledge base affects litigation activity. The results are therefore relevant to all firms that participate in patenting activity in emergent technology areas such as biotechnology or genetic engineering.

The main finding of this paper has practical implications for two constituencies. One, managers of business units should be careful while patenting intellectual property in the area of business methods especially if they are taking an options approach to such patenting. A business method patent provides the right to sue but the exercise of this right is not appropriate under all circumstances. Our findings suggest that a firm holding a high-value patent should disclose as little as possible while a low-value patent should have as much information as possible. Two, researchers and administrators of US R&D policy need to ensure that patent examiners have done due diligence in terms of prior art search to ensure that such patents are not likely to be litigated. Both the above implications are reflected in announcements by firms and recent policy changes announced by the U.S Patent and Trademark Office (Bukeley, 2001). These announcements suggest that more attention is being paid to business method patents both during the application process as well as after their grant.

NOTES

1. See Lerner (2002) and Boldrin and Levine (2002) for a recent discussion on these issues.
2. It can be argued that the purchase price of the real option should also include the expenses incurred in developing the underlying technology. That said, such expenses should be included only when the investment is to be considered as an option. In our paper, we consider the patent as an option to sue, which is distinct from the option to invest.
3. This is different from costs of continuing with the litigation that could be substantially higher and a function of not only the type of intellectual property involved but also the parties involved.
4. Business method patents have been issued only after February, 1998. However, the US Patent Office reclassified patents issued before this date. We include these patents in our analyses.
5. This may not seem like a high number but is significantly higher than the pharmaceutical sector that had 252 litigations for approximately 50,000 patents.
6. We computed the citations per year variable based on citations up to the end of year 2002. We are not concerned about publicity effects (citations post-litigation) as Lanjouw and Schankerman (2001) demonstrate that such effects are minimal (accounting for a maximum of 10% of citations) and tend to wear off with time. We could compute citations up to the point of litigation for patents that get litigated, but given our rare event methodology we could not compute equivalent values for the randomly chosen sample.
7. An ideal approach would be to use an event history model to test the likelihood of litigation. However, given the small number of events and the large number of spells, we prefer using a far more conservative and robust modeling approach of rare events logit analysis.
8. See Fleming and Sorenson (2002) for an excellent application of rare events to a situation similar to this paper.

9. It is interesting to note that in the full Models X and XIV the only interaction that remains significant is that of value with academic knowledge. This suggests that disclosure through academic prior art is the one that is most easy to understand for infringers from a 'fence' perspective as well as a 'building block' perspective.

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MANAGING A PORTFOLIO OF REAL OPTIONS

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ABSTRACT

This study analyses the determinants of the value of a portfolio of real options and explores implications for strategic management. It focuses the analysis on four elements: the number of real options in the portfolio, constraints on the number of options that can be exercised, the volatility of underlying assets, and the correlation between underlying assets. These elements are articulated around a trade-off between growth options and switching options and are applied to different strategic situations of technological, market, and macroeconomic uncertainty.

Firms that are vying for future competitive advantage in highly dynamic environments focus their activities around "exploring new opportunities and building capabilities" that are potentially valuable, but where value is certainly not assured (March, 1991). Incumbents in such businesses have a difficult choice: In building their portfolio of exploration-oriented investments, they may face a critical trade-off between flexibility and commitment (Christensen, 1997). While too much commitment can put the firm in

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a vulnerable financial situation, a failure to invest erodes its future competitive advantage (Levinthal & March, 1993; March, 1991). The real options lens has emerged as a potential tool to solve the trade-off between flexibility and commitment, considering strategic investments as options for future strategic choices (Bowman & Hurry, 1993). In this view, strategic investments create discretional opportunities that, similarly to financial options, can be exploited discretionally. Kogut (1991) pioneered this approach asserting that joint ventures are analogous to real options since they limit downside losses while allowing the appropriation of most of the upside gains. Managers ''exercise'' the option by acquiring the venture, in other words, a call option. Several other studies have extended Kogut's initial work to different contexts. Examples are Chang (1995) with internationalization processes, Miller and Reuer (1998) with foreign exchange rate movements, and Mang (1998) with R&D investments.

In spite of these advances, the literature is still in its initial stages regarding the understanding of *portfolios* of strategic investments. The seminal research of Bowman and Hurry (1993, pp. 762) has recognized that 'the option lens provides a view of an organization's resources – its capabilities and assets – as a bundle of options for future strategic choice'. More recently, it has been pointed out that firms often undertake a portfolio approach to their exploration-oriented investments rather than considering them as independent options (Vassolo, Anand, & Folta, 2004). For example, it has long been known that firms in technologically dynamic environments tend to invest simultaneously in multiple and parallel R&D projects (Nelson, 1961). This observation has important implications for the analysis of R&D projects as real options. Yet most real options research in strategic management has not explicitly formalized portfolio effects in real options analysis. Some studies have accounted for portfolio dimensions, such as number, size, scope, and prior investments (e.g., Hurry, Miller, & Bowman, 1992; McGrath & Nerkar, 2004; Reuer & Leiblein, 2000), but they have not analyzed the nature of the interactions among real options and their effects on portfolio value. Indeed, the size of the portfolio and the levels of uncertainty generate a complex structure of pay-offs where each strategic investment may alter the boundary conditions of other strategic investments (McGrath, 1997). For example, in the case of pharmaceutical or biotech research, firms may invest in multiple real options corresponding to multiple approaches to treating a particular medical condition. Over time, one of them may emerge as the dominant paradigm for treatment while others may not turn out to be fruitful investments. In the field of computing, telecom and other related technologies, one might have a similar substitutive effect among investments in different technologies, e.g., in the cases where only one dominant standard emerges. But there can also be a complementary effect among technologies, e.g., when the establishment of a dominant design makes other compatible technologies more attractive. For such portfolios of interrelated real option investments, the task of assessing the value of each investment and the optimal composition of the portfolio is complex, but important.

To the extent that strategic management literature has addressed issues related to real options portfolios, two aspects have emerged: interactions among individual real option investments, and the nature of uncertainty. The first aspect relates to the presence of *interactions* among different real options within a portfolio of investments. In the presence of interactions, the valuation of a portfolio of simultaneous real options is not straightforward. McGrath (1997), in a study regarding technology-positioning investments, suggests that the cross-effect of uncertainty of one strategic alliance on the boundary conditions of other strategic alliances should be included in the valuation of the portfolio. Following McGrath's suggestion, Vassolo et al. (2004) have tackled this issue, pointing towards the sub-additive and super-additive effect of multiple options under "winner takes all" conditions. Their work insinuates that the presence of multiple and overlapping options might add marginal value or may imply overinvestment under different conditions. Treating equity alliances as growth options, they observe that the exercise of an option significantly alters the value of the remaining options in a portfolio. If so, the analysis of a single option without taking into consideration "portfolio effects" might lead to inappropriate conclusions.

A second aspect relates to the different *sources of uncertainty*. While initial studies on real options mainly focused on growth opportunities, recent studies have pointed that not all sources of uncertainty lead to growth. As MacMillan and McGrath (2002) and Oriani and Sobrero (2002) have stressed, while some sources of uncertainty generate *growth opportunities*, other sources might induce *switching opportunities*. For example, when technology is the source of uncertainty, switching opportunities may be critical in such a competitive context. Instead, when market demand is the main source of uncertainty, growth opportunities may dominate the strategic decision. Therefore, a firm's portfolio of strategic options must seek the adequate level of investment in switching and growth options depending on the levels of different types of uncertainty. These two types of real options are particularly important since they well represent the trade-off between flexibility and commitment.

While growth options stem from early commitment in growth opportunities (Ghemawat, 1991), switching options provide the firm with an essential form of flexibility in face of different sources of uncertainty.

Our goal in the present study is twofold. First, we want to systematically present the different elements that determine the value of a real options portfolio by reviewing the most relevant studies on financial and real options, with a particular emphasis on the interaction effects among both the options and their underlying assets. Second, we want to provide insights for scholars and managers regarding the configuration of a real options portfolio in the presence of different sources of uncertainty. In particular, we intend to investigate under which conditions it can be convenient for a firm to invest in a wider set of exploration investments. To achieve this goal, we begin by reviewing portfolio related studies in the real options literature. This allows us to identify the salient elements of a portfolio of real options as well as the expected relationships among them in the existing literature. Following that, we develop a framework for understanding portfolio effects and provide a set of propositions. Our overarching goal is to understand how the portfolio framework can help scholars and managers to make superior strategic assessments and decisions with respect to investments with highly uncertain returns.

Our main conclusion is that the value of a portfolio of simultaneous strategic options is mainly a function of growth and switching opportunities, and the relative value of each type of options depends on the specific source of uncertainty. In order to illustrate these conclusions, we propose the most effective configurations of the portfolio for different contexts such as R&D investments, new market entry, and international investment decisions. These applications have the advantage of providing contrasting optimal configurations of the portfolio. We believe that the study of portfolio properties is one of the aspects of the real options applications to strategic management that needs substantial development and that has the potential to provide an exciting avenue for advancement in the near future.

The paper is organized as follows. In the next section we review the relevant literature related to real options portfolios. In the following two sections we build our propositions, concerning the value and the composition of a portfolio of real options, respectively. Finally, in the concluding section, we discuss the main contributions and the limitations of the paper.

THEORETICAL BACKGROUND

While firms can create value by committing their real assets, the value of such investments can be highly uncertain. The strategic interest in real options mainly lies in the possibility of truncating the distribution of the uncertainty in the value of investments. Real options are those investments that allow for the full realization of a certain value without fully committing, up-front, the investment until the relevant uncertainty is resolved. In highly uncertain environments, such as technological investment, foreign investment, or investments in emerging economies, the real options approach to strategic investment sounds appealing. The truncation of the distribution function favors investments with higher levels of volatility in the expected returns, suggesting that the volatility parameter (σ) is critical for valuing these investments.

As the use of real options has become widely accepted both in the literature of strategic management and in managerial practice, more sophisticated challenges have emerged. In particular, while most of the analysis focuses on a single option, most firms simultaneously invest in multiple options (Nelson, 1961; Vassolo et al., 2004). Even though several studies have recognized that the overall value of a firm critically depends on its portfolio of growth options (e.g., Kester, 1984; Myers, 1977), the issue of potential interactions among real options has been so far scarcely investigated. The presence of interactions among real options implies that it is not enough to make decisions regarding real options one by one focusing on its own volatility (e.g., Luehrman, 1998; takes this approach), but to include interactions as the key element in real options management (MacMillan & McGrath, 2002). Stated differently, the challenge is to recognize what is unique about portfolios and to incorporate this uniqueness into the assessment of the portfolio value or strategic contribution.

In this paper, we claim that a portfolio effect exists when the value of a real option is contingent upon the value of other real options in that portfolio. For ease of explanation, we focus on simultaneous real options. The interest of analyzing the portfolio effect lies in the non-additivity property that it generates: the value of the portfolio differs from the value obtained by linearly adding the different real options. In principle, the portfolio effect happens when at least either one of the two following conditions holds: First, there is a correlation among the expected returns of the underlying assets. We refer to this correlation as ρ. For example, the numerical analysis of Triantis and Hodder (1990) shows that the value of the real option embedded in a flexible manufacturing program grows when the values of the goods that can be potentially produced are inversely correlated. Similar results are obtained by Boyle and Lin (1997) in evaluating contingent claims on multiple correlated underlying assets. The second condition is the existence of a constraint on the exercise of some of the real options in the portfolio. In this case, if n is the total number of real options in a portfolio and m is the number of options that can be exercised, we would have $m<n$. Such a situation may take place, for example, when there is a capacity constraint limiting the pursuit of different investment opportunities.

It can be seen from this analysis that the presence of a portfolio effect expands the critical parameters in the real options analysis from a focus on volatility (σ) to also the inclusion of the correlation (ρ) between the expected returns of the underlying assets, and the number of real options n and the number of options that can be exercised m. Before presenting the framework that integrates all of these elements, we briefly review previous studies regarding the two kinds of portfolio effects just described.

Correlations among Real Options in a Portfolio

The evaluation of a portfolio of multiple correlated assets has been addressed in different studies in finance. Margrabe (1978) has extended the basic model of Black and Scholes (1973) to evaluate a switching option. The value of this option depends on the opportunity to exchange one existing asset with a new one, the values of the two assets following correlated stochastic processes. The formalization of Margrabe (1978) shows that the value of the option negatively depends on the correlation among the expected returns of the two assets (i.e., it is greater when the correlation is negative). Another seminal analysis in this regard is the one by Stulz (1982). He develops the first formal model that values the exotic option on the minimum or maximum of two assets. This option combines two call options with a switching option. Comparative static results show that the value of the switching option is maximum when the correlation is –1 and minimum when the correlation is 1, i.e., the value of the option to switch diminishes as the underlying assets are more positively correlated. Johnson (1987) expands Stulz's model for the case of n assets and obtains similar results. In the same vein, Boyle and Lin (1997) show that when a contingent claim is written on multiple assets, the correlations among assets have to be taken into account. Their numerical analysis shows in particular that positive correlations among the assets reduce the value of the option as compared to the case of no correlation.

With respect to real options, Triantis and Hodder (1990) have developed a model for valuing flexible production systems that embeds these two issues: correlations and switching among multiple assets. In this case, the system can produce either one of the two goods whose values follow correlated stochastic processes. The reason why the firm has to choose one of the two products is the existence of capacity constraints, which are analogous to contractual constraints in the exotic options of Stulz (1982) and Johnson (1987). The numerical analysis performed by the authors show that the value of the portfolio decreases when correlation increases. Following the same logic, Lint and Pennings (2002) have developed a model to evaluate the option to invest simultaneously in two competing technological standards, of which just one will succeed. Their analysis finds that the value of this option decreases with correlation. This result is consistent with those illustrated above and reinforces the idea that a portfolio of real options can be non-additive when there is a constraint on the exercise of contingent claims and the assets have non-zero correlation.

Constraints on Option Exercise in a Portfolio

In several cases it is possible to observe constraints on the exercise of the options in the portfolio. Laamanen (2000) explores this situation. He extends the model of Johnson (1987), considering a situation where the investor can choose the m best of n assets, with $1 \leq m \leq n$. This situation is analogous to a portfolio of n investment opportunities of which m can be undertaken, with m determined by the firm's exercise capacity. However, Laamanen's model assumes that the assets have zero correlation. Notwithstanding the absence of correlation among the assets, the author finds non-additivity in the portfolio of real options when the number m of assets that can be picked is fixed and lower than n. Bengtsson and Olhager (2002) obtain similar results in a model for valuing flexible production systems with capacity constraints, and without considering the correlations among the assets.

Vassolo, Ravara, and Connor (2005) reinforce the previous results, but within a different setting. They model an oligopolistic game in which each firm invests in multiple real options for developing different markets. Demand grows following a geometric Brownian motion process. Even though each market demand evolves independent of other markets demands (i.e., zero correlation), non-additivity in the portfolio emerges as a consequence of capacity constraints for attending different demands. Their main contribution is to show that in a model with competitive interaction, with constraints on the number of options that can be exercised and have even no correlation of the underlying assets, new options have a decreasing marginal value. Therefore, all these results help highlight the fact that non-additivity can stem from eventual constraints on the exercise of real options independent from correlations.

In sum, formal studies on portfolios of real options have stressed the importance of recognizing the presence of non-additivity when: (1) real assets are correlated; or (2) when constraints on the exercise of different options exist. It is interesting to examine to what extent managers recognize this property and build their portfolios accordingly. Empirical studies that investigate the portfolio in applications of real options to strategic management are rather scarce, but they show interesting evidence.

McGrath and Nerkar (2004) have remarked how the R&D portfolio characteristics can affect firms' choices to invest in new technological areas. In particular, they have found a negative association between previous cumulative knowledge in given technological areas and firms' propensity to take growth options in new technological areas, as measured by patents in new technological classes. This is seminal evidence about strategic behavior that is adjusted to interactions in real options, even though their analysis focuses on sequential interaction while we are focusing on simultaneous interaction.

Vassolo et al. (2004) have explored the concept of sub-additivity and super-additivity in a portfolio of simultaneous real options, understanding equity alliances as real options. Following Folta (1998), who shows that alliances represented by a minority equity position can be considered a real option, they have studied alliance formation and termination within a portfolio of technological overlapping alliances. In particular, they have analyzed how large pharmaceutical companies ally with small biotechnology labs in a patent-race or winner-take-all context. They have observed that, for a given portfolio of related strategic alliances, the presence of an acquisition significantly enhances the probability of observing divestiture in the related alliances. This phenomenon was characterized as sub-additivity, since the exercise of one real option (i.e., acquisition of the alliance) diminishes the value of the remaining real options. This study considers each portfolio as n assets on which just one option can be exercised (i.e., $m = 1$). Since the n technologies are mutually exclusive, their values are inversely correlated. The option is Stulz's derivative of the maximum on several assets where the exercise of one option significantly erodes the value of the remaining options. The main contribution of Vassolo et al. (2004) is to test real options behavior in strategic decisions in the presence of correlation between the underlying assets. Their findings seem to indicate that certain strategic decisions follow the rationale embedded in a portfolio of correlated strategic options. This study, however, is very specific to the type of portfolio analyzed, i.e., perfect negative correlation among the underlying assets and complete substitutability of the technologies.

Several conclusions arise from this section. First, interaction between real options can stem from correlations among the underlying assets or from exercise constraints. While the mechanisms that affect portfolio value differ, both have the same implication of introducing non-additivity in the valuation. Second, given the non-additivity property, the analysis of a portfolio of real options should involve three parameters in addition to the volatility level of the expected returns of the underlying assets (σ): the number of underlying assets (n), the number of real options that can be exercised on these underlying assets (m), and the correlation among the expected returns of the underlying assets (ρ). Third, *the value of a portfolio of simultaneous real options depends not only on the growth potential of each asset but also on the possibility to switch among these assets.* That is, we expand the traditional emphasis on growth opportunities to the necessity of considering switching options, which are at the root of the portfolio effect due to the presence of correlation or of constraints in the number of options that can be exercised. These conclusions offer the basic elements for the development of a general framework for analyzing a portfolio of strategic options.

EVALUATING THE PORTFOLIO

We define a *real options portfolio* as a set of n growth options of which m can be undertaken, such that $1 \leq m \leq n$ (see Laamanen, 2000, for a similar interpretation). The value of this portfolio is ultimately linked to the value of the underlying assets that can be acquired through potential exercise of the growth options included in it. A *growth option* exists when a firm has the right, but not the obligation, to acquire a new asset (i.e., the present value of future cash flows) through a subsequent investment (e.g., Kester, 1984; Kulatilaka & Perotti, 1998). The value of each growth option in the portfolio depends on the value of the specific underlying asset that can be acquired. Moreover, according to the previous discussion on the truncated distribution of the option pay-offs, the volatility of the underlying assets (σ) is a key value source of growth options. When there are no constraints on the exercise of the growth options (i.e., $m = n$), the value of the portfolio is simply the sum of all the growth options in the portfolio. In fact, in this case, all the growth options can be potentially exercised and all the underlying assets acquired.

However, when m is lower than n, several portfolio effects arise. First, the value of the portfolio does not increase linearly with the value of the growth options, since only some of them can be exercised and therefore only part of the underlying assets can be acquired. Second, the value of the portfolio is related not only to the value of the growth options themselves, but also to the possibility of switching among underlying assets (switching options). When $m<n$, in fact, a firm has the possibility to pick the best m assets over the n possible ones (i.e., it can exchange the $n-m$ worse assets with the m best assets). The *switching option* is therefore the opportunity to exchange a real asset (for example, the present value of the future cash flows from an existing technology) with a potentially more valuable one, for example, the present value of the future cash flows from a new technology (Oriani & Sobrero, 2002). The value of the switching option is contingent upon the difference among the values of the assets that can be eventually exchanged.

Fig. 1 illustrates how growth and switching options coexist within a real options portfolio. When $m = n$ (left), the real options portfolio is composed only of independent growth options. As the exercise of each growth option does not affect the exercise of the other options, the value of the portfolio is a linear function of the value of the single options and no switching option exists. When, instead, $m<n$ (right), fewer than the number of available options can be acquired due to the presence of some exercise constraint. The value of the single growth options is lower because, ceteris paribus, each option will have a lower probability to be exercised (sub-additivity).

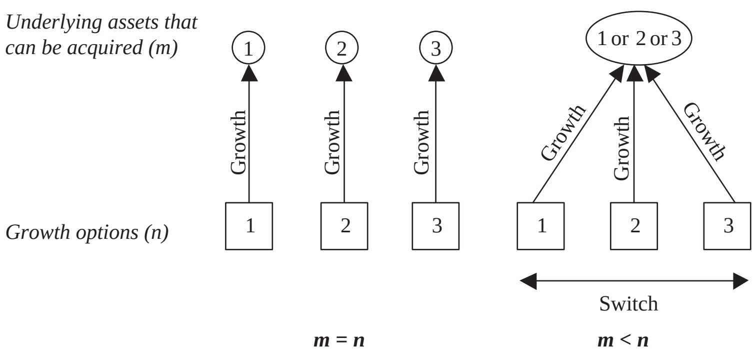

Fig. 1. Growth and Switching Options in a Real Options Portfolio.

However, this portfolio embeds an option to switch among the three underlying assets, which is similar to a financial option on the maximum of n assets (Johnson, 1987). Its value, therefore, will depend on both growth and switching options.

A further portfolio effect is that a non-zero correlation among the underlying assets affects the total combined volatility of the underlying assets (see for example the formal models of Margrabe, 1978, or Stulz, 1982) and therefore portfolio value. When, in fact, the underlying assets to be exchanged have correlated expected returns, the expected differences among their values can be higher or lower than in the specific case of zero correlation. In this paper, consistent with the financial models evaluating contingent claims on several assets (e.g., Johnson, 1987), we assume that the expected returns of the n underlying assets have bivariate correlations $-1 \leq \rho \leq 1$. We understand that this correlation is the main source of the switching value since it ultimately affects the difference among the expected values of the assets to be exchanged.

Examples of real options portfolios with different n to m ratios and correlation levels are reported in Table 1. In the first row, we have portfolios without exercise constraints ($m = n$). This means that all the growth options are independent and can be potentially exercised. For example, in quadrant

Table 1. Different Real Options Portfolios (n = Number of Options in the Portfolio; m = Number of Options that can be Exercised; ρ = Correlation between the Returns of the Underlying Assets).

	$\rho < 0$	$\rho = 0$	$\rho > 0$
$m = n$	I. A firm without capacity constraints has invested in two countries ($m = 2$, $n = 2$) with negatively related GDP growth rates ($\rho < 0$)	II. A pharmaceutical firm has invested in two independent therapeutic areas ($m = 2$, $n = 2$) whose markets have independent growth rates ($\rho = 0$)	III. A firm without financial constraints can scale up its initial investment in two industries ($m = 2$, $n = 2$) with positively related growth rates ($\rho > 0$)
$m < n$	IV. A firm has invested in two competing technologies, of which only one will be implemented ($m = 1$, $n = 2$, $\rho < 0$)	V. A flexible plant with limited capacity can produce either one of two products ($m = 1$, $n = 2$), whose markets have independent growth rates ($\rho = 0$)	VI. A firm with financial constraints has the opportunity to scale up its investment in one of two different markets ($m = 1$, $n = 2$) with positively related growth rates ($\rho > 0$)

II, the development of a new drug in a therapeutic area does not preclude the development of a drug in the other therapeutic area. In the second row, instead, the growth options are interdependent due to the presence of some form of constraint. In quadrant IV, the development of one technology will kill the development of the other one. There is therefore a constraint related to a winner-take-all situation. Moreover, given that the two technologies are perfectly alternative, their values are negatively correlated. In quadrants V and VI the exercise constraint is related to production and financing capacity, respectively.

Taking together with the portfolio parameters, we express the *value of a real options portfolio* (PV) as a function of four variables

$$\mathrm{PV} = f(\sigma, m, n, \rho) \tag{1}$$

The main observation derived in the previous section was the presence of a non-additivity property in the valuation of a real options portfolio under some given conditions. The goal of the current section is to derive a set of propositions regarding the impact of each of those variables introduced in Eq. (1) on the portfolio value, taking into consideration the potential portfolio effects described above.

Overall Volatility

The literature on financial options has broadly recognized that the value of options positively depends on the variance of the expected returns of the underlying assets because of the asymmetric distribution of the option payoffs. Also in the case of real options, the literature has recognized a positive effect of volatility, since they allow a firm to reduce the effects of downsides and enhance the effects of upsides (e.g., Trigeorgis, 1996). This reasoning can be extended to the whole real options portfolio. In fact, the investment in the portfolio is bounded by the sum of the premiums paid to acquire the single options, whereas the potential gains from different options are not bounded from above.

In the field of strategic management, it has been remarked that the value of real options is positively related to the scope of future growth opportunities (McGrath & Nerkar, 2004). In fact, their potential losses are bounded by the initial investments in any case, whereas the potential upside growth increases with expected performance volatility. Within a portfolio perspective, a firm's bundle of options limits its downside risk, while preserving its ability to expand aggressively if the external environment evolves favorably (Bowman & Hurry, 1993; McGrath, 1999; Reuer & Leiblein, 2000). In this sense, the value of a real options portfolio should critically depend on the ratio of the upside potential to the downside exposure.

It seems then clear that greater volatility of the expected results increases the value of exploring new markets or technologies independent of the presence of any constraint on the exercise of some options or the presence of correlation among underlying assets. Therefore,

Proposition 1. Ceteris paribus, the value of a real options portfolio will monotonically increase with the volatility (σ) of the expected returns of the underlying assets.

This proposition is straightforward and it is at the base of most of the applications of real options to strategic management. It emphasizes the growth potential of a portfolio. With no correlation or capacity constraints, another proposition follows. Since the growth options are independent and their pay-offs structure is truncated (non-negative), the value of the portfolio will linearly increase with the number of growth options embedded in the portfolio. Therefore,

Proposition 2. Ceteris paribus, the value of a real options portfolio will monotonically increase with the number of growth options (n).

That is, higher levels of volatility favor larger portfolios and this increment has no clear upper-limit. This pattern is altered when capacity constraints and correlations come into play. In this case, as we observed in the previous section, the value of the portfolio not only depends on the growth options, but also on the possibility of switching between assets.

Exercise Constraints

The literature on real options has often implicitly assumed no decreasing value of the new options added to a portfolio. However, the presence of constraints on the number of real options that can be exercised increasingly affects the marginal value of real options. This is because the value of a real options portfolio ultimately depends on the exercise of the options. It will be valuable for the field of strategic management if we could identify which types of constraints may affect the portfolio and how these constraints affect the value of a real options portfolio.

We identify three main constraints to the exercise of real options: first-mover advantages, capacity constraints, and financial constraints. Lieberman and Montgomery (1988) define first-mover advantages in terms of the ability of pioneering firms to earn abnormal returns. They mention three primary sources of first-mover advantages: (1) technological leadership, (2) preemption of assets, and (3) buyer switching costs. The strategic dilemma is to balance the necessity for being first with the over-investment that might result from this "race." In the case of technological leadership, for example, if the firm can develop and market a non-imitable product trough a patent, it will race to do so, since the winner will dominate the market for the new good (Mitchell, 1989). In the extreme case, when just one technological solution can be accepted by the market, a winner-take-all situation predominates, where only the first mover will stay on the market (see Reinganum, 1983). The exercise of a technological option, therefore, will kill all the other competing options (Vassolo et al., 2004), so that just one over n potential technologies will be effectively implemented.

Second, there can be production capacity constraints limiting the number of investments that can be pursued (e.g., Triantis & Hodder, 1990; Vassolo et al., 2005). Realistically, firms cannot increase their production capacity in the short term. This means that some market opportunities, even if profitable, cannot be pursued due to the impossibility to expand the production beyond a given threshold.

Third, even if the production capacity can be expanded, a firm can face financial constraints when planning new investments (i.e., lack of credit and/or equity financing). When financial markets are imperfect, firms may not be able to raise capital to finance profitable investments (Hubbard, 1998). Due to information asymmetries between firms and external investors, this constraint is likely to be tighter for more uncertain investments, such as R&D (e.g., Hall, 2002), or for more innovative firms that have not internal financial resources (O'Brien, 2003).

This presence of constraints implies that over n growth options, only m can be effectively undertaken. Therefore, when m is fixed, adding new growth options to the portfolio has a decreasing marginal value (see also Laamanen, 2000). This implies that when n becomes greater than m, the value of the portfolio will increase at a decreasing rate with the addition of new growth options. This is because the value of the portfolio ultimately depends on the exercise of the options, and each new option that is added to the portfolio, with m fixed, has a lower exercise probability (see also Fig. 1). Notice that the marginal value may still be finite and positive due to the option to switch among these alternative choices. In a different perspective, when m is higher and close to n, which means that nearly all growth options can be exercised, each growth option will have, ceteris paribus, a higher value because then its exercise is more likely. This means that the higher m, the higher the effect of n on portfolio value. Accordingly,

Proposition 3. The number of exercisable growth options (m) positively moderates the relationship between the number of growth options (n) and portfolio value.

That is, we recognize a clear effect of constraints on the value of the portfolio. When the number of options that can be exercised is bounded, the value of the option portfolio increases when new growth options are added, but mainly because of the switching value, as we will see in the next section.

Correlation among Underlying Assets

The most complex effect is the one related to the correlation among the underlying assets. Failure to consider the effect of correlation would lead to underestimation of the value of the switching options. As shown by the mentioned studies on exotic options (e.g., Stulz, 1982), the value of the switching option on several underlying assets grows with negative correlation. Indeed, it is rather intuitive that a portfolio of real options on positively correlated underlying assets has different expected returns as compared to a portfolio of real options on negatively correlated ones. This is particularly true when a firm has a constraint on the number of options that can be exercised. In this case, the potential number of assets among which a firm can choose is greater than the number of assets it can invest in (i.e., $m<n$). Therefore, since a firm is switching from the $n-m$ worst assets to the m best assets, a negative correlation among the n underlying assets increases the value of picking the m best assets, whereas a positive correlation has the opposite effect. Notice that a positive correlation among these options can be interpreted as a complementary relationship among them rather than the more common case of substitutive relationship as implied in the case of negative correlation. Intuitively, when the underlying assets are negatively correlated, the firm can reasonably expect that the m best assets will be worth significantly more than the $n-m$ worse assets. Instead, when the assets are positively correlated, their values move together, so that the expected difference between the m best and the $n-m$ worse assets is lower. This line of reasoning emphasizes how the value of switching

opportunities is negatively related to the correlations among the underlying assets, independent from the value of the specific growth options. Therefore, we propose:

Proposition 4. With $m<n$, the value of a real options portfolio will monotonically decrease with an increase in correlation (ρ) among the expected returns of the underlying assets.

The inverse relationship between correlation and portfolio value is essentially due to the value of the switching option. Its magnitude, however, depends on how much the switching options are important for portfolio value. As explained above, the switching value of a portfolio of real options depends on the constraints to the exercise of the growth options. In particular, the lower is the number of exercisable options, the higher is the value of switching some underlying assets with other assets. Therefore, the switching value is maximum when just one option can be exercised, whereas it is equal to zero when all the growth options can be exercised (i.e., $m = n$), because in this case the single growth options are independent and no switching opportunities arise. This reasoning leads to the conclusion that the effect of correlation on portfolio value is stronger when m is lower and the portfolio embeds more switching options. Accordingly.

Proposition 5. The number of exercisable growth options (m) negatively moderates the relationship between correlation (ρ) and portfolio value.

The set of propositions presented in the current section and depicted in Fig. 2 is the result of a systematization of the existing results in the literature on portfolios of financial and real options. They have the role of individuating the elements to be considered to build real options portfolios. Moreover, they show more clearly how the value of a real options portfolio depends on two sources of value: growth and switching. When the number of exercisable options diminishes compared to the number of growth options in the portfolio, the value of growth decreases due to the lower exercise probability of the individual options, whereas the value of switching less valuable with more valuable underlying assets increases. All these propositions have important implications for strategic management, but they do not directly refer yet to competitive advantage. The next section further develops the implications of these ideas for strategic management by providing a set of propositions regarding building effective portfolios.

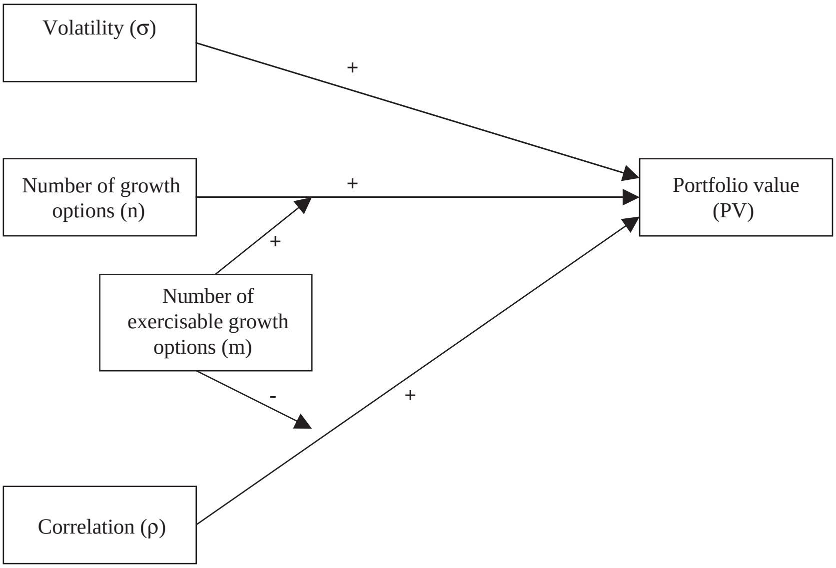

Fig. 2. Factors Affecting Portfolio Value.

BUILDING EFFECTIVE PORTFOLIOS

The current section further develops the main implications of the propositions derived in the previous section regarding the factors affecting the value of a real options portfolio for strategic management. Building effective portfolios relates to balancing the two value sources of a real options portfolio: growth and switching. The propositions in the previous section show in this respect that this implies deciding whether to invest in positively or negatively correlated assets (ρ) and choosing the number of growth options (n) in relation to the given exercise constraints (m). We define the ratio n/m as the *portfolio width*. Different choices about correlation and portfolio width impact the value of growth and switching options in different ways. First, although the marginal contribution of new growth options can be very low when n is large compared to m, there can be incentives to add new options due to the switching value. That is, increasing portfolio width can add value to the portfolio due to the creation of an option to switch among several assets. Second, investing in negatively correlated assets increases switching value, but it reduces the whole potential upside of the growth options in the portfolio. In fact, when the correlation among the assets is positive, i.e., when they are complementary, a positive shock makes the values of the underlying assets likely move upward together, so that all the growth options are likely to be "in the money" (i.e., they have a positive value). On the contrary, with negative correlation, it is likely that when a part of the values moves upward, another part will move in the opposite direction, so that only a smaller fraction of the growth options will be "in the money."

In this section we claim that a correct balancing of the growth and the switching values is context-specific. An important aspect to be considered in this perspective is uncertainty. As discussed above, in fact, given the truncated distribution of the option pay-offs, the option value increases in the level of volatility (i.e., uncertainty) of the expected returns of the underlying asset. Here a relevant distinction between the studies in corporate finance and strategic management emerges. Whereas the former use the variance of the expected returns as an aggregated measure of the total volatility of an asset, in strategic management uncertainty is a broad and multidimensional concept that usually stems from different sources (e.g., Milliken, 1987). Therefore, our main argument in this section is that the choice of n and ρ and therefore the balancing between growth and switching value can critically depend on the source of uncertainty we take into consideration.

A first important distinction that has been made in the applications of real options to strategic management is that between market and technological uncertainty (e.g., MacMillan & McGrath, 2002; Oriani & Sobrero, 2002). *Market uncertainty* derives from the volatility of demand and the variability of customers' needs. Unexpected variations of either one of these dimensions can deeply affect market size and then the expected cash flows from the commercialization of innovation (Iansiti & Clark, 1994). *Technological uncertainty*, instead, jeopardizes firms' decisions beyond market uncertainty (Anderson & Tushman, 2001). Given the expected level of demand, managers must choose the technology to embody in the firm's products (Krishnan & Bhattacharya, 2002). Since the established technology often competes with one or more emerging technologies, they will be uncertain about which technology will be adopted as a standard in the future (Tushman & Rosenkopf, 1992). The higher the number of alternative technologies and the more unpredictable their performance, the higher the technological uncertainty will be.

A relevant implication of the distinction between market and technological uncertainty is that the two sources of uncertainty can affect the value of switching and growth options very differently. In the model of Oriani and Sobrero (2002) market uncertainty affects the value of growth options, whereas technological uncertainty is relevant for the value of the switching options. The value of a growth option increases with market uncertainty because while the possible loss is limited to the initial investment, the potential gain from future growth opportunities has no upper bound (Folta & O'Brien, 2004; Kulatilaka & Perotti, 1998). When the uncertainty mainly concerns alternative technologies, an option to switch has a high value because it reduces the negative consequences of investing in the wrong technology (Hatfield, Tegarden, & Echols, 2001; MacMillan & McGrath, 2002; McGrath, 1997; Oriani & Sobrero, 2002; Vassolo et al., 2004).

A third important source of uncertainty in real option applications to strategic management, mainly concerning the analysis of international expansion investments (e.g., Chang, 1995; Reuer & Leiblein, 2000), is *macroeconomic uncertainty* (Kogut & Kulatilaka, 1994). In this paper, we refer in particular to the exploration challenges faced by companies investing in emerging economies (Anand, Brenes, Karnani, & Rodriquez, 2006; Kahai, 2004; Kohers, Kohers, & Pandey, 1998). Two aspects characterize the macroeconomic environment in emerging economies: sharp variation in the gross domestic product and high variation in relative prices of the products. Macroeconomic uncertainty is relevant to real options analysis because abrupt changes in the basic conditions of a national economy can impact on the present value of the expected cash flows of a strategic investment (i.e., the value of the underlying asset of a growth options) independent from market and technological uncertainty (Kogut & Kulatilaka, 1994).

In the next sections we will analyze how each source of uncertainty can impact on the characteristics of an effective portfolio of real options.

Technological Uncertainty

Technological uncertainty is relevant for those firms that have to decide among alternative technologies for a given product and market.[1] In this respect, two issues are particularly relevant: the correlation among the values of the competing technologies and the first mover advantage that will lead just one or few technologies to survive. As technological uncertainty progressively resolves, the value of the winning technology will grow, whereas the values of the other technologies will drop. Those firms that have not invested in the right technology are at risk of being locked out of the market (Cohen & Levinthal, 1990; Hill & Rothaermel, 2003). In fact, when the new technology emerges as a dominant standard in the industry, they will neither be able to competitively sell products based on the established technology nor to re-enter later in the market embodying the new technology into their products (Schilling, 1998). Based on these arguments, we advance that in presence of high technological uncertainty, a firm has then two reasons to invest in a fairly large number of competing technologies. The first one is the negative correlation of the values of the competing technologies (Proposition 4 predicts a positive relationship between negative correlation and portfolio value), due to the fact that when a technology progressively emerges as dominant design, the value of the other ones will significantly decrease (Vassolo et al., 2004). Second, as just one or very few technologies will succeed, a tight exercise constraint (low m) reinforces the effect of negative correlation on portfolio value (see Proposition 5).

Taken together, these two explanations converge in suggesting that a firm facing high technological uncertainty has incentives to invest in a portfolio of many negatively correlated assets even in the presence of tight constraints on the exercise of these options. In fact, due to high negative correlation among the underlying assets, the value created by the new switching options is greater than the loss induced by the reduced exercise probabilities of the growth options (see also Fig. 1). In other words, a firm facing high technological uncertainty has greater incentives to create switching options to hedge against the risk of lockout even though the growth value is negligible. Indeed, using the variables defined in the previous section, n will be large, but m will be small, and the portfolio is characterized by a large coefficient n/m. Moreover, the bivariate correlation coefficients ρ will generally be negative. Therefore,

Proposition 6a. Ceteris paribus, real options portfolios of firms facing high technological uncertainty will be taken on negatively correlated assets ($-1 \leq \rho < 0$).

Proposition 6b. Ceteris paribus, real options portfolios of firms facing high technological uncertainty will exhibit larger width (n/m).

Market Uncertainty

The situation for firms facing market uncertainty is different from technological uncertainty for what concerns both the correlations among the assets and the interdependence among the options. First, the choice of different markets on which to create growth options depends on firm-specific factors. In particular, the products a firm can sell in different markets are deeply rooted in its set of core competences (Barney, 1991; Prahalad & Hamel, 1990). These competences lead to a competitive advantage in a given market only if they adequately match the strategic factors of that market (Amit & Schoemaker, 1993). Therefore, there exists some strong relationship between the markets where a firm can achieve a competitive advantage. Even in the dynamic perspective provided by real options theory, new market exploration normally involves related markets. Investments in exploration create new capabilities, which are options on future market opportunities (Bowman & Hurry, 1993). The process of exploring new capabilities moves however from existing capabilities through a local search process (Gavetti & Levinthal, 2000; Kogut & Kulatilaka, 2001). Market relatedness will therefore significantly influence the decision to enter into a new market (Folta & O'Brien, 2004). Second, even though there can be exercise constraints related to production capacity or financing sources, they are weaker relative to the first mover advantage related to alternative technologies. In other words, a firm should be able to compete in several non-competing markets since the entry into a market does not automatically preclude the entry into other markets.

The likely relatedness between the markets on which a firm creates growth options and the looser exercise constraints suggest that in the presence of high market uncertainty, a firm will hold a portfolio of growth options on positively correlated assets (i.e., markets with positively correlated expected growth rates) or at least on non-correlated assets (i.e., markets with independent expected growth rates) to exploit the potential upside of market volatility, whereas it is very unlikely that the underlying assets are negatively correlated. In addition, with positive or zero correlation, the potential switching value would be low (Proposition 4), so that the portfolio will focus mainly on the growth value pursuing the upside potential. Given Propositions 2 and 3, this means that it is convenient to choose n close to m, so that portfolio width will tend to be close to its minimum value (i.e., the ratio n/m will tend to 1). In the case of lower or zero correlation, a firm could find it convenient to increase portfolio width to gain some switching value. However, the ratio n/m will never be as high as in the case of technological uncertainty, where we had strong negative correlation due to a winner-take-all situation. Therefore we advance the following:

Proposition 7a. Ceteris paribus, real options portfolios of firms facing high market uncertainty will be taken on positively correlated assets, or at the limit, on non-correlated assets ($0 \leq \rho \leq 1$).

Proposition 7b. Ceteris paribus, real options portfolios of firms facing high market uncertainty will exhibit smaller width (n/m).

Macroeconomic Uncertainty

Macroeconomic uncertainty concerns those firms taking growth options on the same markets, but in different countries (Kogut & Kulatilaka, 1994; Markides & Ittner, 1994). In particular, in this paper we are interested in investments in emerging economies, given the sharper variations of the macroeconomic conditions in these countries (Anand et al., 2006; Kohers et al., 1998).

The two most relevant aspects to analyzing a real options portfolio of investments in emerging economies are the level of macro-economic uncertainty and the level of correlation among the underlying assets (i.e., correlation among the expected GDP growth rates of the countries). Since market variations are sharp and relative prices follow these market variations, a wise decision seems to seek options on negatively correlated underlying assets in order to hedge against macroeconomic uncertainty (Akdogan, 1996). In such a case, the firm would be able to switch investments from countries with unfavorable economic conditions to countries with more favorable conditions. This decision would imply sacrificing growth potential in favor of switching opportunities.

But switching options are also difficult to find. In general, growth rates in emerging economies are positively correlated to each other, though sometimes not very strongly. Therefore, although we are unlikely to find countries with perfectly negatively correlated GDP growth rates, in order to increase switching value a firm should favor those countries whose growth rates are at least not strongly and positively correlated (see Proposition 4).

Overall, this situation favors the creation of larger portfolios (high n) compared to the existing exercise constraints (m) to enhance the switching options. Given however the non-complete substitutability of international investments and the weaker negative correlation among the underlying assets, we expect that this effect will not be as strong as in the case of technological uncertainty. Therefore, we advance the following:

Proposition 8a. Ceteris paribus, real options portfolios of firms facing high macroeconomic uncertainty will be taken on negatively correlated assets, or at the limit, on non-correlated assets ($-1 \leq \rho \leq 0$).

Proposition 8b. Ceteris paribus, real options portfolios of firms facing high macroeconomic uncertainty will exhibit a larger portfolio width (n/m).

DISCUSSION AND CONCLUSIONS

In this paper we have analyzed the factors explaining the value of a real options portfolio and the implications for its strategic management. We have recognized that portfolio effects arise from two issues: interdependence among the exercise of the single real options (e.g., exercising one option kills other options in the portfolio) and correlation among the expected returns of the underlying assets. In doing that, we have tried to explain why firms can choose portfolios with different width or with different correlation among the underlying assets. We have also shown that under some context-specific circumstances, it can be convenient to add new options to the portfolio even though, due to strong first-mover advantage, only one option can be exercised in the end.

We believe that this paper provides at least three important contributions to the existing literature on real options portfolios. First, moving from financial models valuing exotic options (e.g., Stulz, 1982), it has explicitly recognized that the value of a portfolio depends on both growth and switching options. In particular, taking independent options on positively correlated underlying assets increases the growth value, whereas creating competing options on negatively related assets increases the switching value. Neglecting the switching value would lead to an erroneous estimation of portfolio value and to misleading conclusions about its effective composition. Focusing just on the growth potential of a portfolio would suggest, for example, a reduction of the investments in competing technologies, thus exposing the firm to the risk of technological lockout. This result is consistent with the literature reporting underinvestment in new technologies by incumbent firms (e.g., Christensen, 1997).

Second, based on the above-mentioned distinction between growth and switching options, we have articulated the factors affecting the value of a portfolio of real options. Whereas some of them are straightforward and conventionally treated in the real options literature (such as volatility, σ), size (n), exercise constraints (m), and correlation (ρ) are relatively new to the applications of real options theory to strategic management. While both capacity constraints and correlation had been taken into consideration by the finance literature (e.g., Triantis & Hodder, 1990), their strategic implications for a real options portfolio have been scarcely investigated so far. Considering only volatility as a main source of portfolio value might lead again to misleading conclusions under several circumstances.

Third, moving beyond the analysis of the factors affecting portfolio value, we have derived a set of general propositions on the effective composition of a real options portfolio. Consistent with our theoretical framework, building an effective portfolio implies balancing growth and switching values. We assumed that growth and switching values depend on two main strategic decisions: portfolio width (measured by the ratio between total growth options and exercisable options) and correlation among the underlying assets. The main argument we made in this respect is that this balance is critically affected by the relevant source of uncertainty that a firm faces. We complement a previous study by Oriani and Sobrero (2002) who remarked how market and technological uncertainty affect distinct real options. In this paper we have analyzed the effect of three different sources of uncertainty (market, technological, and macroeconomic uncertainty) on two critical features of the portfolio: width and correlation among the underlying assets. The main insights we can gain in this respect from our propositions are summarized in Table 2. In the presence of high technological uncertainty, the values of the underlying assets (i.e., competing technologies) will be negatively correlated, and a firm will find it convenient to increase switching value through the creation of a wider real options portfolio. This result reinforces the idea of McGrath (1997) that in the presence of uncertainty on the future dominant design, investing in competing technologies provides the firm with valuable technological hedging. Facing high market uncertainty, firms will pursue growth value creating a tighter and high variance portfolio on positively correlated underlying assets. In the case of macroeconomic uncertainty, we have an intermediate situation. A firm will tend to hedge against country risk trying to invest in countries with negatively related macroeconomic trends. However, given the difficulty in finding countries with highly negatively correlated GDP growth, the magnitude of correlation will be lower than in the case of technological uncertainty and the portfolio tighter.

Even though our analysis can be generalized to many different strategic situations, it does not embrace some other potentially relevant issues. In the case of technological uncertainty we assume a specific context of portfolios of

Table 2. Sources of Uncertainty and the Characteristics of Real Options Portfolios.

	Technological Uncertainty	Market Uncertainty	Macroeconomic Uncertainty
Portfolio width (n/m)	Large	Small/medium	Medium/large
Asset correlation (ρ)	Negative	Zero/positive	Zero/negative

competing substitute technologies consistent with the patent race scenario. However, if the portfolio consisted of complementary rather than substitute technologies, we would have positive rather than negative correlations among the underlying assets, and the results would be significantly different.

Further, we have not included in the portfolio analysis some types of real options, such as waiting options (e.g., McDonald & Siegel, 1986) or abandonment options (e.g., Majd & Myers, 1990), even though the switching options implicitly embed abandoning some assets to acquire different ones. Moreover, we analyze the properties of a portfolio of simultaneous real options and implicitly assume no temporal connection between contingent claims. In this sense, we do not take compound options into consideration (i.e., options on options, see Dixit & Pindyck, 1994). These real options could be particularly interesting since previous literature has recognized that a firm's strategy unfolds through the sequential exercise of related options (Bowman & Hurry, 1993). In the same vein, McGrath and Nerkar (2004) have shown that there exists a relationship between new and existing real options. With respect to our conclusions, analyzing the sequential interactions among real options could add further insights into the determinants of firms' choices on portfolio width and asset correlation. Future research avenues could, therefore, build on the current study and on some of the new research analyzing the choice of sequential/simultaneous development of investment projects in finance (Childs, Ott, & Triantis, 1998; Childs & Triantis, 1999; Grenadier & Weiss, 1997) and strategic management (McGrath & Nerkar, 2004), to include new issues into the portfolio analysis.

The use of real options in strategic management has shown to be fruitful for more than a decade. The academic world has gained understanding about dealing with uncertainty and the trade-off between flexibility and commitment. Portfolio considerations have been hidden for the better understanding of the application of real options to strategic investment. We think that it is time to explicitly address what is unique about portfolios and how this affects strategic behavior. The present study is an attempt to provide a solid basis for understanding strategic decisions from a portfolio of real options perspective.

NOTE

1. Our focus here is on competing technologies that are mutual substitutes rather than a portfolio of complementary technologies. In the case of complements (e.g., in the case of network externalities), we would find different results.

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PART IV: ORGANIZATIONAL AND MANAGERIAL DIMENSIONS OF REAL OPTIONS

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CAPABILITIES, REAL OPTIONS, AND THE RESOURCE ALLOCATION PROCESS

Catherine A. Maritan and Todd M. Alessandri

ABSTRACT

In this paper, we consider the relationship between the investment decision process and returns to investments in capabilities. We draw on characteristics of capabilities to develop a framework that identifies four components of the returns to an investment that are derived from industry-based versus firm-specific elements, and option and non-option elements. We then link these components to elements of the resource allocation process. In taking this approach we place the study of real options into the larger investment context, recognizing that they co-exist with and should be understood in conjunction with other investment characteristics. These arguments highlight the importance of connecting the investment process with realization of returns, thereby providing the conceptual foundations for a decision tool.

Resource allocation is a fundamental activity of management and therefore it has long been of interest to strategic management scholars. In the past decade or so, real options theory has made significant contributions to how

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we study resource allocation and the particular investments made by firms. There has been a great deal of attention paid to conceptual issues and there is an increasing body of empirical studies (see Li, James, Madhavan, & Mahoney, 2007; Reuer & Tong, 2007 for summaries). Although the real options literature in strategic management is largely about resource allocation, with few exceptions, it generally does not address the resource allocation *process*.

Here we explore links between real options and the resource allocation process (RAP). To do so, we focus on a particular type of investment, namely investments in capabilities. Our choice of capability investments as a vehicle to make this link is based on several factors. First, capabilities have been described as having real options characteristics (Kogut & Kulatilaka, 2001), therefore, any investment in a capability should take this feature into account. Second, as we explain below, investments in capabilities are often made by way of investments in physical assets, for example, production equipment (Baldwin & Clark, 1992). This means that the real option can be embedded in an investment with non-option features, thereby, placing the option investment in the context of a firm's regular capital investments. In addition, when a firm invests in a capability, it may be trying to achieve a firm-specific benefit from purchasing an asset available to any competitor. This characteristic presents some challenges for investment decision-making and the RAP (Maritan, 2001). In sum, investments in capabilities provide a rich context for our exploration.

We draw on characteristics of capabilities to develop a framework that distinguishes different components of the returns to an investment that derive from industry-based versus firm-specific elements and option and non-option elements. We then link these components to the elements of the RAP. In doing this we integrate literature on capabilities, real options and the RAP to develop a better understanding of investment decisions.

INVESTING IN CAPABILITIES

What does it mean to invest in a capability? Consider a common definition of a capability. A capability is a firm's capacity to deploy its resources, tangible or intangible, to perform a coordinated task or activity in an effort to achieve a performance outcome (Amit & Schoemaker, 1993; Grant, 1991; Helfat, 2003). Arguments in the literature (e.g., Dierickx & Cool, 1989; Grant, 1991) suggest investment as a means for developing capabilities. However, capabilities tend to emerge over time through complex interactions among resources and are embedded in a firm's routines, processes and culture. Because of this they are generally non-tradable in factor markets (Amit & Schoemaker, 1993; Dierickx & Cool, 1989). So, if firms do not purchase capabilities, what does it mean to invest in a capability?

Baldwin and Clark (1992, p. 68) suggest that investments in capabilities "do not stand alone, but are intertwined with other investments." Building on that insight, Maritan (2001) analyzed capital investments in terms of the capabilities that a firm was attempting to build via investments in physical assets. She argues that if we understand how the constituent resources contribute to a capability, then the investments in those resources can be characterized as investments in the associated capabilities.

Consider the following example of a firm investing in a piece of production equipment. The firm may be investing in additional capacity simply to meet increased demand for its product. Or, it may be investing in a type of equipment that enhances its capability to be flexible enough to change its product mix on short notice to be more responsive to customers. Even if the investment is intended to increase capacity rather than provide flexibility, it may be an investment in the capability to achieve lower production costs from exploiting economies of scale, or in the capability to use capacity as a competitive weapon to deter entry or expansion by competitors. Purchasing the same capital equipment can be viewed very differently depending on the capability investment associated with the equipment investment. Characterizing capital investments in terms of the organizational capabilities to which the purchased assets contribute has implications for managing the investment decision-making process and for valuation.

However, a question remains: How can a physical asset that can be purchased by a competitor lead to a competitive advantage? If factor markets are functioning efficiently, the price of an asset is the discounted present value of that asset. How then can a firm generate economic profit from purchased assets available to its competitors? The answer is that a firm must see valuable opportunities that either competitors do not see or it can exploit while competitors cannot.

This situation may arise if the firm has information that generates more accurate expectations than competitors about the future value of the assets (Barney, 1986; Makadok & Barney, 2001). Alternatively, the firm may use the assets in different ways than competitors would, for example, in combination with complementary assets controlled by the firm (Barney, 1991; Denrell, Fang, & Winter, 2003). For example, Barney (1991, p. 110) notes that "(s)everal firms may possess the same physical technology, but only one of these firms may possess the social relations, culture, traditions, etc. to fully exploit this technology in implementing strategies.'' This suggests that when a firm makes an investment in a capability by investing in constituent resources, the return to that investment has two components, a general component that is available to all competitors making a similar investment plus a firm-specific component due to a combination of superior information and complementarities.

A capability, by its nature, has a range of potential future uses in addition to its current uses. Bowman and Hurry (1993) argue that a firm's capabilities represent a bundle of options for future strategic choice. There is uncertainty about the value of a capability in future uses. Future applications of the capability will require additional investment; however, the firm has the choice of whether or not to make the investment to use the capability in these future ways. Should conditions not be favorable for the future application, the additional investment does not have to be made. When characterized in this way, we can see that a capability can be viewed as a real option.

Capabilities are platforms or positions that represent investments in future opportunities in that they provide opportunities to respond to future contingent events (Kogut & Kulatilaka, 1994; McGrath, 1997). Therefore when a firm makes an investment in a capability, it is investing in a currently planned application of the capability as well as contingent future applications. This suggests that the return to that investment has two components, the return from using the capability in the currently planned application plus an option value.

With these issues in mind, we develop a framework that decomposes the returns to an investment in a capability into separate components. We first separate industry-based returns from firm-specific returns. Within each of those components we make a further distinction between steady state returns based on current conditions and option value based on future conditions. Fig. 1 illustrates the framework.

Components of Returns to Capability Investments

A firm makes an investment in a capability through the purchase of an asset, expecting a return on that investment. Robins (1992) separates the return to an asset into two components – the market-determined return to the asset and the firm-specific return that results from combining the focal asset with other assets in the firm. The market-determined return is capitalized in the price of the asset. The firm-specific return represents an increase in the performance of the asset above its market value and a potential competitive

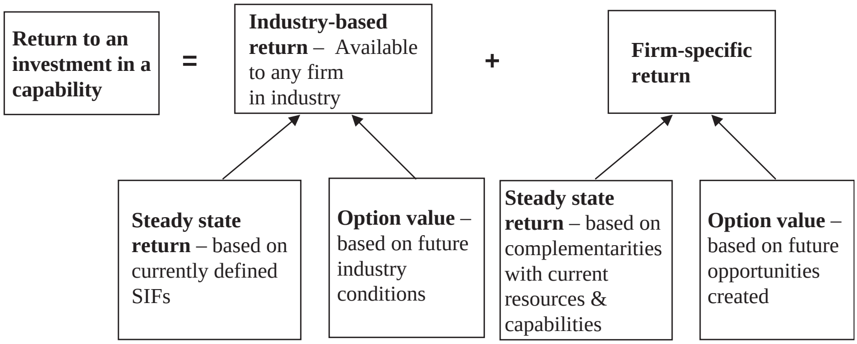

Fig. 1. Components of the Return to a Capability Investment.

advantage. Given that capabilities involve complex combinations of assets making them not readily tradable in factor markets, the concept of a market-determined return to a non-tradable capability investment is not very meaningful. However, we can draw on an industry-level versus firm-level distinction made by Amit and Schoemaker (1993) to adapt Robin's logic to investments in capabilities.

Amit and Schoemaker (1993) propose that each industry has non-tradable, industry-specific factors that are the prime determinants of rents available to be earned in the industry. They label these "strategic industry factors" (SIFs). They also define firm-level factors that determine actual rents earned by individual firms. Integrating the arguments of Robins (1992) and Amit and Schoemaker (1993), we propose that returns to capabilities investments have two components. First, there are returns that would be available to any firm in the industry that invests in the capability, which we label as the industry-based return. Second, there are additional returns that a particular firm can achieve due to interaction of that capability with its stock of other resources and capabilities, which we label the firm-specific return. This distinction between industry-based and firm-specific returns to a single investment is analogous to the distinction made in the literature between industry-level and firm-level effects contributing to firm profitability (e.g., Rumelt, 1991; McGahan & Porter, 1997; Brush, Bromiley, & Hendrickx, 1999).

Drawing on the notion of capabilities as real options (Kogut & Kulatilaka, 1994, 2001; Bowman & Hurry, 1993), we propose that each of these components can be further broken down into steady state returns, which comprise current period, and future returns based on current conditions and an option value, which comprises future returns based on future conditions.

Industry-Based Returns to Capability Investments
Typically, expected returns to an investment are calculated from forecasts of incremental cash flows based on revenues derived from demand projections, costs based on organizational resources and capabilities, and supply projections. Implicit in these estimates are assumptions about the external environment. SIFs incorporate the interaction of several key aspects of the industry environment, including competitive conditions, customers, and innovation. In essence, these factors determine which capabilities have the potential to generate rents, as well as the size and duration of those rents. This logic implies that an investment in one of the rent-generating capabilities should produce returns for any competent organization. Thus, a portion of the returns would be available to any firm that could satisfactorily meet customer needs by filling a portion of the customer demand.

The magnitude of these industry-based returns to capability investments is a function of several factors. A higher level of customer demand suggests greater returns. However, greater levels of competition to satisfy that demand can result in the industry competing away a portion of the returns. In sum, there is a potential expected steady state return to a capability investment, i.e., current period and future returns based on existing conditions, which all competent industry players could achieve. Although these returns may be affected by demand, competition, and structural changes, we refer to these returns as "steady state" because they are based on existing customer needs and current opportunities in the industry. Individual firms may vary in their abilities to insulate themselves from these forces, thereby differentially benefiting or suffering from their effects. These firm-specific abilities contribute to firm-specific returns, which we address later.

In addition to the steady state industry-based return, there is also an industry-based option component in many capability investments. Investing in capabilities can provide firms with flexibility options or growth options (Kogut & Kulatilaka, 1994). Firms in the industry can employ a capability in which they have invested, such as production automation, if conditions prove favorable. In terms of growth, capabilities can represent platforms from which to enter new markets (geographical or customer). For example, as firms have developed capabilities in digital technology, we have witnessed a convergence of several industries – computers, telecommunications, television, photography and entertainment (Baker et al., 2004). By investing in the digital technology capability, firms have acquired an option to compete in this converged arena when demand increases to a sufficient level. In addition, the convergence provides industry participants with a new set of customers – telecommunications firms now can cross-sell products to entertainment consumers. We view these returns as industry-based because they arise from industry level conditions, and opportunities are potentially available to all industry participants. Kester (1984) refers to these as shared options.

Firm-Specific Returns to Capability Investments

In addition to the industry-based returns available to a firm making a capability investment, there are returns that arise from the use of the capability by that particular firm. This firm-specific component of the return represents quasi-rents, the incremental value in excess of the value that could be realized in the asset's next best use (Klein, Crawford, & Alchian, 1978). The next best use in this instance would be the use of the asset by other firms. Like the industry-based component, the firm-specific component can be separated into a steady state return based on assets in place and an option value.

The steady state component of firm-specific returns to a capability investment is in addition to the industry-based steady state return, and reflects the incremental cash flows that relate to the firm's use of that specific capability. In other words, given the current skills and knowledge of the organization, how much value can the capability investment provide? For example, if a company is investing in equipment using a new technology that will allow it to produce its products more efficiently, what are the incremental cash flows associated with the implementation of that new technology? These cash flows may be difficult to accurately value, however, it is important to acknowledge these flows exist.

The firm-specific steady state return is affected by (1) complementarities between the capability acquired through investment and the firm's existing resources and capabilities (Amit & Schoemaker, 1993; Milgrom & Roberts, 1990; Teece, 1986) and (2) the isolating mechanisms that protect the combination of resources and capabilities from imitation (Rumelt, 1984). The value of a newly acquired capability therefore depends in part on the degree and nature of complementarities with other resources and capabilities of the firm. Firms can leverage their existing capabilities in combination with the new investment, enhancing the value of the latter. In addition, the newly made capability investment may be able to be utilized by multiple areas of the organization. Thus, the interaction of the capability investment with preexisting firm-specific capabilities may provide a substantial component of value. Consequently, the heterogeneous distribution of resources and capabilities across firms has important implications for differential valuations of similar capability investments made by different firms.

The option value component of firm-specific returns relates to the ability of the firm to profit from the capability investment in future opportunities.

While this firm-specific option value is analogous to the option component of industry-based returns, there is an important difference. At the firm level, the return from the option value is determined by the firm's preferential access to its own stock of existing resources and capabilities when the new capability investment is pursued (Bowman & Hurry, 1993) rather than by industry-level factors. Trigeorgis (1996) and Kester (1984) refer to this type of option as a proprietary option. While industry-based and firm-specific option values are both a function of changes to competitive conditions and how the capability is used to exploit future opportunities, the main trigger for generating the option value differs in each case. In the industry-specific case, the option value is generated by applying the capability in alternative industry conditions. In the firm-specific case the option value is generated by one or more of: (1) an ability to generate more option value than industry competitors in the alternative industry conditions due to the firm's resources and capabilities; (2) alternative combinations of the acquired capability and other assets and capabilities controlled by the firm; and (3) asymmetric expectations among firms competing in the factor market about how future conditions will evolve.

A firm may be able to leverage the focal capability investment to create future opportunities, which Myers (1984) calls time series links. Kogut and Kulatilaka (1994) refer to an investment that provides these future opportunities as a platform investment and McGrath (1997) views it as a positioning investment. Other sources of firm-specific option value can result if (1) the focal capability investment provides management with greater flexibility to manage environmental uncertainties, and/or (2) future conditions, such as a shift in technology or consumer preferences, prove favorable to the focal investment. In all cases, the investing firm is in a better position to take advantage of future opportunities. Continuing the earlier example of an investment in efficient production equipment, this efficiency may position the firm to take advantage of changes to competitive conditions or to withstand potential changes in customer demand. In addition, by improving efficiency, a firm may be able to improve its reputation with customers, leading to other sources of profit.

Some Examples

To illustrate the framework, we consider two examples: a classic one from the literature and one from our own research. In the 1980s, firms began to invest in advanced production technologies such as flexible manufacturing systems (FMS). FMS uses microprocessor-based industrial machinery such as machine tools that can be readily programmed and reprogrammed. FMS is used to manufacture efficiently several types of parts using the same equipment (Jaikumar, 1986). The technology in the equipment permits firms to offer more product variety to its customers or to customize products to meet customer requirements at lower cost than would be possible with traditional production equipment (Kaplan, 1986). When a firm invests in FMS equipment, the capability in which it is investing is manufacturing flexibility.

The return to this investment in flexibility can be decomposed into an industry-based return available to any firm that buys the equipment plus a firm-specific return that reflects the complementarities with other pre-existing firm resources and capabilities. Using FMS equipment requires, for example, specially trained workers, appropriate incentive systems, expertise in software programming, and interactive decision-making processes, and there is evidence that some firms are better able than others to provide these complementary resources and capabilities to effectively implement FMS (Hayes & Jaikumar, 1988). To take advantage of the flexibility FMS equipment provides also requires product development and design capabilities that enable the firm to manufacture the product features that meet customer needs. Varying abilities to provide these required complementarities among firms that purchase the same equipment will result in varying firm-specific returns to the same investment. Indeed, many early adopters of FMS were unable to use the equipment they purchased effectively due to lack of complementary resources and capabilities (Hayes & Jaikumar, 1988).

The return to this investment in flexibility can also be decomposed into steady state return and option value. Some of the serious difficulties with the application of standard capital budgeting models surfaced in the study of how firms justified investments in FMS (Kaplan, 1986; Dean, 1987). It was difficult to justify these investments because certain anticipated benefits were difficult to evaluate ex ante. The return to the investment in flexibility includes benefits from not only serving current customers with more customized products but also from the ability to respond to future shifts in market demand, should they occur. That is, there is a steady state component and an option value.

Some potential future opportunities to take advantage of the FMS manufacturing flexibility are industry-wide. The flexibility inherent in the programmability of FMS extends the usefulness of the equipment beyond the life cycle of the products for which it is acquired (Kaplan, 1986). This option to meet future demands for different product characteristics is available to all firms in an industry and is therefore a shared or industry-based option.

However, due to the existence of important complementarities as mentioned above, the returns to the investment also include firm-specific option value. For example the combination of the flexibility arising from the FMS system and a firm's capabilities in product development and design may allow it to leverage its development and design expertise to satisfy emerging customer needs better than competitors can.

Another example is one taken from our field research. Integrated Paper, a large US paper company, made an investment in equipment to incorporate recycled fiber into one of its paper products. A major customer requested that the paper it purchased to use in the manufacture of greeting cards contain a portion of recycled paper material rather than all virgin wood pulp. Using recycled paper lowers input costs but presents challenges to achieving a high-quality printing surface on the paper. The capability investment underlying this equipment investment was the technological expertise to use recycled inputs to produce a high-quality printing surface for demanding applications. The expected return from this project exhibited the four components described in our framework. The steady state return derived from the cash flows arising from manufacturing and selling the recycle-content paper to the greeting card maker that had made the initial request and forecasted sales to another existing customer who had a high likelihood of purchasing the output.

Other competitors could and did invest in similar equipment but could not achieve as good a printing surface on their products. Integrated Paper had superior complementary papermaking skills and knowledge it was able to draw upon, and this contributed to there being a firm-specific component to the steady state return over and above what others in the industry could realize. There was also a firm-specific option value. Integrated Paper planned to use this initial investment in combination with its superior papermaking capability to learn about incorporating recycled paper into its products. The goal was to eventually include recycled material in other types of paper with high quality requirements for other customers if the technology proved to be viable for those applications. Integrated explicitly recognized this option element of the investment and although the managers did not use the term option, they did include the option rationale in the capital budgeting proposal.

Descriptions of the returns components for these projects are summarized in Fig. 2. Although we can define the four returns components in our framework, the relative proportion of the overall return represented by each of the components will vary with the particular investment as our examples illustrate. The difficulties that many firms had justifying investments in FMS

A. Investment in Flexible Manufacturing Equipment

	Industry-Based	**Firm-Specific**
Steady State Current period & future returns based on existing conditions & resource position	Basic use of the equipment taking advantage of shorter set-up times to achieve increased product variety (RELATIVELY SMALL)	Complementarities with trained workers, software programming expertise, customer relationship management (RELATIVELY LARGE)
Option Value Future contingent returns (Exercise will require additional investment)	Response to new market demands (RELATIVELY SMALL)	Complementarities with product development and design to work with customers on emerging needs (RELATIVELY LARGE)

B. Investment in Equipment to Use Recycled Pulp in Papermaking

	Industry-Based	**Firm-Specific**
Steady State Current period & future returns based on existing conditions & resource position	Sales of paper with recycle content (RELATIVELY LARGE)	Complementarities with superior papermaking skills – Paper high enough quality for greeting cards for current customer and planned new sales to another customer (RELATIVELY LARGE)
Option Value Future contingent returns (Exercise will require additional investment)	(NONE APPARENT)	Explicit plan to learn to use recycled pulp for other future high quality applications beyond greeting cards (RELATIVELY SMALL)

Fig. 2. Examples of Components of Returns to Projects.

were due to the relatively large proportion of the expected return that was due to option value (Kaplan, 1986). The steady state return alone was often not sufficient to meet the decision criteria. This option value included both industry-based and firm-specific components. Unlike the FMS example, it is not clear whether there was an identifiable industry-based option component to Integrated Paper's investment, or only a firm-specific option. In addition, the option value was estimated to be much smaller in magnitude than the steady state return.

THE PROCESS OF INVESTING IN CAPABILITIES

Up to this point, we have focused on the components of the potential returns to a capability investment. Now we turn to factors that affect the degree to which a firm has the opportunity to earn those returns. Organizational processes strongly influence the ability of a firm to obtain the potential returns to an investment. The Bower-Burgelman (B-B) model of the RAP (Bower, 1970; Burgelman, 1983; Bower & Gilbert, 2005) provides a useful lens for examining the firm-level process of investing in capabilities.

The B-B model describes a complex, multi-stage investment process in which managers at multiple levels of a firm play distinct roles. The three elements of the RAP are labeled definition, impetus, and the structural and strategic context. Definition is a cognitive process that typically is initiated when operating level managers, based on their technological or market knowledge, identify a performance-related discrepancy, such as a cost, quality or volume shortfall, and seek to address the discrepancy through investment. Alternatively, definition might be triggered by a perceived investment opportunity. The managers who identify the need for investment determine the scope and features of the project, expressing them in technical and economic terms. Maritan (2001) found that definition of some capability investments was initiated by more senior managers, rather than operating level managers, particularly when the investment was in a capability that was new to the firm. Definition is followed by impetus, which moves the project toward approval and funding. Impetus is a sociopolitical process that is largely driven by middle managers who must decide whether or not to support the project and then guide it through the organization to senior level managers for approval. Overlaying definition and impetus is the structural and strategic context, which consists of organizational and administrative mechanisms that affect behavior and set strategic priorities and direction, thereby providing the organizational setting within which resource allocation occurs.

Here we focus on the definition process. Definition involves identifying and specifying the technical and economic features of an investment project and the distinctions made in our framework are most relevant to this stage. This is not to say that the other subprocesses of the RAP model are unimportant. Impetus is a sociopolitical process and is less directly connected to project specifications than is definition. Therefore, it is more difficult to specify relationships between impetus and the returns components. Elements of the structural and strategic context are best viewed as moderators of the relationship between the definition (or impetus) and the returns components. Here we do address a subset of these contextual elements in terms of how they interact with elements of definition.

We next consider several aspects of the definition process and link those aspects to the identification and analysis of the returns components. Although the underlying characteristics of an investment project will fundamentally determine the potential returns available for the firm to earn, the definition process will affect how the project features are specified, the returns associated with those features and therefore the returns that the firm can realize. Here we consider search routines, opportunity recognition, information collection, and the moderating effects of organizational controls (see Table 1). While this list of elements is not intended to be comprehensive of the entire definition process, it does capture important aspects of specifying a project.

Process Levers for Managing Returns Components

Search Routines

Definition is often triggered when operating level managers recognize a discrepancy between what their business is supposed to do and what it can do. For example, discrepancies can take the form of quality issues, cost issues, or capacity shortfalls (Bower, 1970). Here we are particularly concerned about capability discrepancies, where business units lack the skills and routines necessary to fulfill their objectives. Once the discrepancy becomes apparent, the operating managers begin to look for possible solutions to this problem.

Managers at the operating level are specialists (Bower, 1970). They possess a relatively narrow area of expertise and will likely search within that area. This process is similar to the notion of problemistic search (Cyert & March, 1963) and therefore would most likely begin with local search in the neighborhood of existing alternatives. Local search also implies several things about the nature of the capability investment that the search will uncover.

Because the search is in the neighborhood of existing alternatives, potential investments will likely involve extending or refining existing practices and processes. The narrow band of specialization of searching managers leads to a focus on improving current capabilities rather than searching for new ones; that is, exploitation rather than exploration (March, 1991). The question now becomes: how does local search impact returns to the investment?

Table 1. Links between Definition Process and Returns Components.

Process Levers	Proposed Relationships
Main effects: Aspects of definition	
Search routines: Local versus broad search	Local search benefits industry-based returns more than firm specific returns Broad search benefits firm-specific returns more than industry-based returns • Given firm-specific returns, local search benefits firm-specific steady state returns more than firm-specific option value • Given firm-specific returns, broad search benefits firm-specific option value more than firm-specific steady state returns
Opportunity recognition: Wide versus narrow participation and cross functional participation	Wider participation and cross-functional involvement benefit firm-specific returns • Given firm-specific returns, wider participation and cross-functional involvement in benefit firm-specific option value more than firm-specific steady state returns
Information collection and use: Procedural rationality	Higher levels of procedural rationality benefit steady state returns more than option value
Moderating effects: Organizational controls	
Time orientation: Short-term versus long-term controls orientation	Time orientation of controls moderates the relationships between aspects of definition and returns • Short-term controls positively moderate relationships with steady state returns • Long-term controls positively moderate relationships with option value
Performance relative to aspirations: Above versus below aspirations	Performance relative to aspirations moderates the relationships between aspects of definition and returns • Performance above aspirations positively moderate relationships with steady state returns • Performance below aspirations positively moderate relationships with option value

The neighborhood of existing alternatives consists of the pool of capabilities the business unit already possesses, capabilities possessed by other business units within the firm that are evident to lower level managers, and capabilities that exist in the industry that are somewhat transparent to the focal business unit. The first two are somewhat obvious, but the third set of capabilities might require additional information. As the operating manager searches for potential ways to close the discrepancy, one possible information source is competitor solutions to the same problem. Organizations can learn from the experience of industry competitors and exploit a competitor's previous exploratory investments (Ingram & Baum, 1997). An example of such vicarious learning has been occurring in the auto industry for some time. This provides us with the first implication for returns to capability investments. Since the industry competitors' existing capabilities are somewhat transparent to the focal firm and the focal firm's existing capabilities are also transparent to all industry competitors, local search is more likely to increase the industry-based returns component as a proportion of total returns.

In contrast, broad search routines outside the existing neighborhood of alternatives are likely to have the opposite effect. These broader searches entail seeking potential projects to resolve the discrepancy by looking in areas that involve capabilities that will be new to the firm, and are more likely to be beyond those of industry competitors. This search for new capabilities may be initiated by senior managers who possess more general, less specialized knowledge and expertise than the operating level managers who conduct more local search (Maritan, 2001). Broader search is exploratory in that it consists of seeking alternatives that are more distant from the business unit's current activities (March, 1991). This breadth of search may pertain to search in both new capabilities/technology domains and more distant temporal domains. By moving beyond the existing neighborhood, exploratory investment projects can lead the firm to develop unique capabilities that set it apart from the industry. Thus, while broad search might be associated with increases in both industry-based and firm-specific returns, given the scope of the search, the increase to firm-specific returns is likely to be substantially larger in magnitude than the increase to industry-specific returns.

The effects of search routines also impact the timing and nature of returns to capability investments. As noted above, local search involves refinement and extension of existing firm activities, suggesting exploitation. Exploitation investments tend to lead to relatively predictable returns and stable equilibrium for the firm or business unit (March, 1991). The predictability and stability of returns is indicative of the steady state returns in our model, especially firm-specific steady state returns since we are talking about refinement or extension of the firm's pool of capabilities rather than the industry's pool. In contrast, exploratory alternatives entail innovation where the returns are more distant and uncertain (March, 1991), and may increase flexibility. These are characteristics of real options investments (Amram & Kulatilaka, 1999; Bowman & Hurry, 1993; Trigeorgis, 1996). This suggests that exploration capability investments from broader search routines will increase the option components, especially at the firm level since option investments involve preferential access to future opportunities (Bowman & Hurry, 1993).

Opportunity Recognition

The narrow expertise of the operating level specialist who initiates project definition may have an additional effect on the returns to capability investments. Allison (1971) shows the importance of different perspectives in decision-making, noting that different viewpoints result in the recognition of different factors, which may lead to different conclusions. The narrow expertise of the lower level initiators may limit the ability to recognize the potential value in opportunities or alternatives, or even miss the opportunities altogether. By relying on lower level managers to define projects, firms are limiting their ability to see important potential opportunities that may provide the firm with a competitive edge.

The effects of this tunnel vision can be minimized through increased participation and cross-functional teams. Broader participation by middle managers appears to lead to better decisions and higher performance (Woolridge & Floyd, 1990). These superior outcomes may be due to the fact that new perspectives are brought to bear on the discrepancy, leading to increased opportunity recognition. In addition, Eisenhardt (1999) highlights the role that diversity in decision making teams adds to the process by bringing different viewpoints and asking different questions. She found that diverse teams yielded more effective decisions. The findings of these two studies seem to indicate that wider participation and cross-functional teams during the definition phase can lead to improved investment decisions potentially due to better recognition of opportunities. Better decisions should allow the firm to increase the level of returns to an investment over and above what industry competitors could achieve (all else constant), thereby increasing the proportion of firm-specific returns.

There may also be implications for the level of managers who participate in definition. Although the B-B model assigns that role primarily to operating level managers, Maritan (2001) found that exploratory investments in new capabilities were initiated by senior division or corporate managers. Furthermore, Floyd and Woolridge (1992) suggest that middle manager involvement is different across firms with different strategies – middle managers are more involved in decision making in firms that pursued greater degrees of exploration. This suggests that middle manager involvement may particularly impact the firm-specific option component of returns to capability investments.

Information Collection and Use

Strategic factor market theory provides some insights into the relationship between information collection and investment returns. Strategic factor market theory argues that the only way for a firm to achieve an advantage from an asset acquired in factor markets, other than by luck, is by possessing superior information resulting in more accurate expectations about the asset's value (Barney, 1986). Managers must collect and analyze this information and a superior ability to do so may increase returns (Makadok & Barney, 2001). Particularly important is information about the resources and capabilities a firm already controls, that is, the complementarities between the acquired asset and the existing asset stock which can lead to higher firm-specific returns (Barney, 1986). Based on these arguments though, no distinction can be made between contributions to firm-specific steady state returns and firm-specific option value. However, considering the role of information gathering in the investment decision process provides some insights.

To define a project in technical and economic terms requires that information be gathered and analyzed. Managers process this information to reduce uncertainty (Galbraith, 1974; Tushman & Nadler, 1978). Different types of investments with varying objectives and levels of uncertainty require different kinds and amounts of information (Rogers, Miller, & Judge, 1999) and entail different degrees of analysis (Papadakis, Lioukas, & Chambers, 1998).

The extent of information gathering and analysis, as well as the reliance upon the information, is defined as procedural rationality (Dean & Sharfman, 1993, 1996; Simon, 1976). Taking an information processing perspective, Dean and Sharfman (1996) found that higher levels of procedural rationality led to more effective decisions. Eisenhardt (1989, 1999) also suggests that information gathering leads to the generation of more alternatives and higher performance. These studies indicate that gathering information and use of that information in analysis should lead to better decisions.

The gathering and analysis of information would likely allow managers to better evaluate the capability investment in terms potential benefits and costs, as well as fit with existing capabilities and strategic objectives. This should lead to greater returns. The higher returns may be due to selecting investments with strong steady state returns, or investments with high option value that offer the firm strong potential to derive future returns.

However there may be different degrees to which higher procedural rationality benefits steady state returns versus option value. A key distinction between the expected steady state returns and option value of an investment is the associated uncertainty. Two conflicting arguments have been made in the literature about the relationship between uncertainty and procedural rationality. A high level of uncertainly means there is a lack of information about future events. On one hand, this can lead to increased collection and analysis of the information that does exist, increasing procedural rationality in an attempt to improve the estimate of expected returns (Eisenhardt, 1989). Alternatively, if information about future events does not exist, managers cannot acquire and analyze it; therefore knowing this to be the case, they will not attempt to do so, leading to a decrease in procedural rationality (Dean & Sharfman, 1993). For steady state returns, information to improve the estimate of those returns may exist and therefore increased procedural rationality could be beneficial to increasing returns, consistent with the first argument. However, due to the very nature of option value, information to improve the estimate of that returns component does not exist at the time of the investment, so increased procedural rationality would not be beneficial, consistent with the second argument. If a firm increases the procedural rationality of its definition process, it should benefit the recognition and quantification of expected steady state returns but it unlikely to benefit the option value component of the same investment.

Organizational Controls: Time Orientation and Performance Relative to Aspirations

Although organizational controls fall under the structural and strategic context element of the B-B model, they can be linked to the definition process and have important implications for managing the returns components. Operating level managers who initiate projects infer direction from the established control systems and the measures on which they are evaluated to identify the objectives of senior management. Control mechanisms can encourage or discourage the choice to initiate a project (Marginson, 2002) in that these controls in essence act as a filter indicating which ideas will be supported – acquiring new capabilities or improving existing capabilities for example. Controls can also lead to risk aversion in capital investment decision making (Beekun, Stedham, & Young, 1998). These arguments suggest that controls influence the definition process. Here we consider two aspects of control systems that are particularly relevant to the distinctions we make in our framework, time orientation and performance relative to aspirations.

The time orientation emphasized by senior management represents an important dimension that influences managerial behavior (Fiegenbaum, Hart, & Schendel, 1996). Managerial performance is often evaluated on the basis of achievement of short-term and long-term objectives. Managers can become overly focused on the short-term, neglecting long-term concerns (Levinthal & March, 1993). Controls that emphasize short-term performance or outcomes, which reflect this managerial myopia, can sway search routines. Operating managers would seek to satisfy immediate performance objectives in the definition of capability investments, favoring near-term returns, which will be incorporated in steady state returns, neglecting to fully consider future opportunities with option value. Controls with a longer-term view may influence search toward longer-term exploratory investments with higher option value and more uncertain returns.

The behavioral view of the firm suggests an additional example of the impact of organizational controls on the definition process. Aspirations and expectations represent central elements of behavioral theory and prospect theory arguments. As part of the strategic context, senior management establishes performance targets of different forms at various levels of the firm. These targets are embodied in the control systems. Performance below expectations triggers the search for alternatives that will help the organization improve. Failure to achieve control targets may lead to broader search to provide substantial improvements necessary to reach aspirations. For example, pressure for profits can lead to willingness to increase risk (McNamara & Bromiley, 1997) and a desire to pursue investments with high option value. In contrast, performance above expectations can have the opposite effect, leading to risk aversion. Pursuing option value in capability investments, which typically involve more risk and uncertainty, at the expense of steady state returns may endanger the achievement of control targets. Thus, managers may focus on local search for exploitation investments with more certain steady state returns to ensure that performance remains above expectations.

DISCUSSION

The framework we present in Fig. 1 extends our understanding of investments in capabilities and the nature of the returns to such investments.

Arguments in the strategic factor market (Barney, 1986) and capabilities literature (e.g., Dierickx & Cool, 1989; Grant, 1991) suggest investment as a means for developing capabilities. However, with few exceptions (e.g., Baldwin & Clark, 1992; Maritan, 2001), investing in capabilities other than through R&D (Helfat, 1997) has not been dealt with extensively. Here we explore capability investments and systematically examine the separate components of investment returns.

The framework integrates the concept of investing in real options with the concept of investing in capabilities. Much of the real options research has been focused on identifying and describing the specific types of investments that have important option characteristics and thus require assessment using options approaches. Because of this focus on the option characteristics of an investment along with the associated contingent returns, any non-option element present in the same investment has tended to be neglected. Here we explore the co-existence of these two elements of an investment by considering investments in capabilities.

We draw on insights from the capabilities literature and the real options literature and make two important distinctions. First we differentiate industry-based returns from firm-specific returns. This distinction is based on the fundamental notion of heterogeneity among firms, that is, firms may use the same asset differently due to differences in information or complementary assets. We also differentiate steady state returns from option value. This second distinction is based on the availability of a capability for future contingent uses. Our framework incorporates both of these dimensions because neither on its own is sufficient.

The industry-based versus firm-specific aspect of the framework is important because it is the firm-specific differences that may contribute to competitive advantage. The steady state versus option value aspect is also important in that it recognizes contingent future value over and above the value of an acquired asset in its currently anticipated use. In the real options literature, these aspects have been recognized separately but not in combination. Kester (1984) and Trigeorgis (1988, 1996) recognize the difference between proprietary or firm-specific options and shared or industry-based options. Myers (1977) differentiates assets in place from growth option value. By incorporating both aspects simultaneously as dimensions of a framework, we can make finer grained distinctions that can help identify project features that lead to one type of returns component versus another.

For example, the real options literature has long argued the benefits of identifying option value when making capital investment decisions. Once an option value is identified, the question remains as to whether that option value may lead to a competitive advantage. If there is firm-specific option value then the answer is yes; however, if there is only industry-based option value, then the answer is no. The recognition of an industry-based option value in an investment is important. Even if it does not lead to a competitive advantage, the firm would have to recognize the industry-based option value just to maintain competitive parity.

While industry-based steady state returns are likely to be recognized by any competent firm in an industry, industry-based option value may not be. With few exceptions (e.g., Tong & Reuer, 2006), Kester's (1984) notion of an industry-based option value has not received much attention, particularly in the context of specific investment decisions. Hence, understanding that an investment in a capability theoretically can contain all four returns components, and can help frame an investment decision in a way that allows for the identification of the components that are present. Therefore we suggest that our framework can serve as the conceptual foundation for an investment decision tool that can be incorporated into the investment decision process.

We explored connections between our framework and the RAP, in particular, the definition process. While there are always issues related to implementation after an investment decision is made which can affect realized returns, we suggest that there are also issues related to the definition process that can affect the returns a firm can realize. In the process of definition, the technical and economic features of the project that lead to the different returns components have to be recognized and incorporated into the project specification, for example, the complementarities leading to firm-specific returns and the uncertain future conditions that create option value. If these features are not part of the project definition, it will be difficult for a firm's managers to take actions and make decisions to optimize their contributions to the overall return to the investment. It should be noted here that we are not suggesting that managers maximize the individual returns components. Their overarching goal is to maximize the overall return and we contend that understanding the components of the returns will help them to do so.

We argue that elements of the definition process such as the scope of search routines, the participation of different managers in identifying opportunities, the nature of information gathering practices and organizational controls in place can all affect this recognition of the returns components. Further, these elements of definition can be managed and used as process levers to manage the returns components.

The ideas presented in this paper provide a launching point for future research. Although we provide some illustrative examples, the first area for attention is the systematic empirical testing and validation of the framework. It would be useful to analyze a set of capability investments and explicitly identify the separate components of the returns and the technical and economic features defined in the projects that are associated with the components. In addition, while we have focused on capability investments because of the obvious presence of an option component, the framework may also be applicable to other types of investments. Efforts aimed at identifying the limits to the generalizability of the model may yield benefits for both research and practice.

Future work could also examine the relationship among the returns components. For example, Maritan and Florence (forthcoming) explore the relationship between option value and steady state returns using a formal analytical model and find that that while the returns components themselves are substitutes for each other, as one would expect, the processes of collecting information about the two types of returns are actually complements. While here our purpose is to emphasize the importance of recognizing their separate identities, the returns components arise from the same investment in the same firm and are therefore likely related in many ways. Understanding these relationships may inform investment decisions and the process of making those decisions.

Here we highlight organizational issues related to the initial acquisition of an option. There is other research that focuses on organizational issues related to making option exercise decisions (e.g., Adner & Levinthal, 2004; Coff & Laverty, 2007; Guler, 2007). While it is useful to examine these sets of issues separately, it would be beneficial to consider them together an explore links between the initial decision to invest and the subsequent decision to exercise. For example, how does recognition and characterization of a real option during definition affect its exercise? Does the process of making exercise decisions differ for options that are explicitly recognized during definition versus those that are recognized to exist after the investment is made (e.g., Bowman & Hurry, 1993)?

Another potential area for future research involves the investigation of the individual level cognitive and behavioral aspects of the investment process. For example, what are the roles of managerial experience, prior investment history, and situational factors on the managers in the definition process? How do those effects impact the investment? How do managers cognitively frame real options? There may also be important links between the investment returns components and the other elements of the RAP, namely impetus and the determination of the structural and strategic context.

Our objective in this paper was to bring together ideas about capabilities, real options, and the RAP to identify qualitatively different components of the return to an investment and explore how those components are related to investment decision-making. We focused on investments in capabilities because there are characteristics of capabilities that contribute differently to the return to the investment. In particular, there is an important real option characteristic. In taking this approach, we also put the study of real options back into a complex context by recognizing that they co-exist with and should be understood in conjunction with other investment characteristics. By exploring how recognition of the returns components is connected to the RAP, we suggest the importance of recognizing links between the investment process and the realization of those returns, and provide the conceptual foundations for a decision tool. We believe that these insights can provide useful guidance for research on corporate investments and managers who make investment decisions.

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REAL OPTIONS MEET ORGANIZATIONAL THEORY: COPING WITH PATH DEPENDENCIES, AGENCY COSTS, AND ORGANIZATIONAL FORM

Russell W. Coff and Kevin J. Laverty

ABSTRACT

Scholars have begun to recognize the importance of integrating organizational issues into real options theory. In doing so, some argue that options are inappropriate for evaluating critical strategic investments. In a more in-depth analysis, we argue that the organizational form that an option takes has a profound effect on exercise decisions. When options are initially integrated, organizational elements such as routines and culture become increasingly intertwined over time, raising the cost of abandoning the option – in effect, pushing firms to exercise options. In contrast, initially isolated options become idiosyncratic and more costly to integrate over time – pushing firms to kill them. There are also reputational and social capital effects that may bias exercise decisions beyond the mere consideration of costs, leading to escalation or missed opportunities.

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Accordingly, firms must first be able to manage the associated organizational costs and minimize systematic bias in exercise decisions. Real options theory is moving away from the limitations of the financial options analogy and is increasingly integrated with strategy and organization theory. This shift requires that researchers consider issues such as intermediate organizational forms, external monitoring of exercise decisions, portfolios of competing options, and group process interventions.

Real options theory is often seen as especially appropriate for strategic investments that must be made under great uncertainty, such as creating new capabilities at the heart of the resource-based view (Kogut & Kulatilaka, 2001; McGrath, Ferrier, & Mendelow, 2004). A firm using this approach makes an exploratory initial investment that creates opportunities, but not obligations, for future investments. This exploratory investment is valuable to the extent that it grants access to the upside potential without exposing the firm to the downside risk (McGrath, 1997).

Do real options lead to escalation of commitment? In exploring organizational barriers to using real options, Adner and Levinthal (2004b) suggest this may be a risk. That is, over time, options become obligations absent a clear prior agreement on conditions needed to justify exercise. This suggests that real options may be less effective than proponents suppose for evaluating broad categories of assets central to current strategy theory and practice. In particular, this applies to most knowledge-based assets, since firms cannot evaluate uncertainties surrounding whether and how knowledge can be absorbed and applied without direct experience and active management (Cohen & Levinthal, 1990; Kogut & Kulatilaka, 1994).

This article evaluates the use of real options for investments in knowledge-based assets, a category that is of great theoretical and practical importance. Unlike Adner and Levinthal (2004b), we focus on a range of possible outcomes rather than solely on escalation of commitment. Accordingly, we suggest an array of pitfalls and some solutions for the management dilemmas based on the organizational form that the option takes. Firms investing in knowledge-based options face tradeoffs between the benefits of integrating the option with the core of the firm (Kogut & Zander, 1992) or keeping it isolated (Bower & Christensen, 1995). We describe how this choice of integration initiates a path-dependent process that shapes the alternatives faced at the exercise decision and the processes used to evaluate those choices. A real options approach for knowledge-based assets, then, must incorporate specific processes and structures; it is not simply a valuation technique. Rather than foreclosing research on real options and knowledge-based assets, we find that infusing real options with organizational theory yields many fruitful avenues for further inquiry.

REAL OPTIONS ON KNOWLEDGE-BASED ASSETS: AN ESCALATION MACHINE?

Knowledge-based assets offer a striking contrast to tangible assets such as oil deposits and other natural resources that are the examples used in much of the real options literature. For this reason, Adner and Levinthal's (2004b) contribution raises fundamental issues. If the tendency to escalate means that real options are less applicable to knowledge and other intangible assets, the importance of real options in strategy formulation would be sharply diminished. Options analysis would still be useful for many investments (market entry, initiation of joint ventures, etc.), but they would be relatively less useful for the most critical strategic decisions. To explore these issues, we describe the challenge of investing in knowledge-based assets, present the logic for applying a real options heuristic, and take a close look at Adner and Levinthal's (2004b) arguments.

Firms must maintain *knowledge inventories* because they cannot anticipate exactly what knowledge will be required in the future (Levinthal & March, 1993). This is a problem, because knowledge is especially prone to time compression diseconomies – when the knowledge is needed, it may be too late to begin its development (Dierickx & Cool, 1989). Thus, investments in these inventories must be initiated when their ultimate value is uncertain.

In most situations, knowledge must be transferred and integrated with complementary assets in order to achieve its maximum potential value (Kogut & Zander, 1992). This compounds the uncertainty of investments in knowledge because the firm faces not just uncertainty about the value of a particular asset, but also uncertainty over its ability to achieve synergies. Moreover, decision-makers are often biased against investments in intangible assets for which returns are uncertain and span long time horizons (Bower, 1970; Hayes & Abernathy, 1980; Maritan & Alessandri, 2007; Porter, 1992).

Real options have been of special interest due to their promise as a means to overcome these problems to help firms build and maintain knowledge inventories (Miller, 2002). Real options on knowledge-based assets, like most options applications, are most useful when there is initial uncertainty about the value of a full investment and postponing the decision will allow better information to surface. For example, it is more difficult to estimate the value of implementing a new manufacturing process or gaining new marketing expertise than the value of acquiring the associated tangible assets, for which factor markets provide reliable prices. Uncertainty about whether knowledge can be absorbed and applied may only be reduced through direct experience (Cohen & Levinthal, 1990; Kogut & Kulatilaka, 1994).

However, Adner and Levinthal (2004b) assert that real options are most appropriate when the technical agenda and market application can be fully specified ex ante and the uncertainty to be resolved is exogenous from any managerial actions. Otherwise, uncertainty remaining at the exercise decision creates organizational problems. Managers are not impartial decision-makers. If exercising the option on a favored project cannot be justified, managers may delay the exercise decision to allow more time for option's "true value" to become apparent. Of course, in the case of endogenous uncertainty, the high upside potential requires substantial managerial effort and a failure to achieve the upside may actually imply that managers have been ineffective. While real options may still be useful in evaluating strategic investments, they may not fully deliver on the promise suggested throughout much of the early literature (Adner & Levinthal, 2004a).

Adner and Levinthal (2004b) articulate two key arguments that have not been prominent in the published work on real options. The first is that organizational processes play a role in exercise decisions. In particular, they argue that managers have incentives to keep projects alive. This is especially true as initial costs and maintenance costs are sunk. As managers face subsequent decisions, the incremental amount required will "buy" the full upside potential of the option. As such, managers may make a rational decision to continue investing even though it would be irrational to do so if the full amount of the investment and maintenance costs were known at the outset.

Ultimately, it is their second key argument about organizational processes that paves the way for agency problems: that uncertainty may remain at the exercise decision.[1] Even if the information about the value of exercising the option improves over time, uncertainty creates a situation in which it is logically impossible to prove that keeping the option alive is not a good idea. Adner and Levinthal (2004b) suggest that firms must have rules in place up front so that it can terminate undesirable projects. Without these up front rules, it will be difficult for the firm to terminate any project, because proponents will always argue for continuation, based on the possibility that a given project will eventually pay off, given sufficient time and investment. In essence, they argue that the prospect of uncertainty-enabled escalation is so troubling as to require necessary conditions for real options: ex ante specification of technical agendas and market applications, and uncertainty that is strictly exogenous to the decision process.

We believe that these are important contributions, but that the analysis that Adner and Levinthal (2004b) present is somewhat limited. We argue that the analysis of organizational processes must be expanded. Below, we explore how the organizational form that an option takes may influence outcomes. Importantly, we identify a range of problems including contexts in which firms may fail to exercise options that are "in the money." In so doing, we identify ways that real options logic can be applied more effectively to knowledge-based assets by balancing and managing the organizational form that the option takes.

ORGANIZATIONAL FORM AS A VARIABLE IN REAL OPTIONS OUTCOMES

In this section, we examine how organizational forms interact with real options. We begin with the observation that, unlike financial options or real options on tangible assets, the organizational context is critical for real options on knowledge-based assets. Specifically, a real option is, to varying degrees, linked or integrated with existing organizational units (Coff & Laverty, 2001). At the extremes, a unit might be fully integrated such that its systems are interdependent with those of other units or it may be isolated so that all systems are kept separate (Thompson, 1967). This context initiates a path-dependent process that affects both the choices faced at the exercise decision and the processes through which those choices are evaluated.

Actual organizational experiences with exploratory investments – a key element of a real options heuristic – suggest that integration and isolation are critical elements to real options on knowledge-based assets.[2] For example, 3M has been praised for nurturing diverse opportunities (McGrath & MacMillan, 2000) in the context of existing organizational units. However, their failure to weed their garden earned them the moniker, "Minnesota Mining & Catchall" when McKinsey suggested breaking up the firm (Tatge, 2000). In contrast, Xerox's isolated Palo Alto Research Center is known for a host of promising opportunities that were dropped (PC, mouse, network, etc.); they pruned branches that were yet to bloom. Thus, Adner and Levinthal's (2004b) focus only on escalation may be unfounded. While both 3M and Xerox failed to make effective exercise decisions, the range of possible outcomes from a real options approach may be broader than Adner and Levinthal (2004b) suggest.

To clarify the important relationships at work here, we begin by exploring the extremes of integration (all systems are interdependent with those of other units) and isolation (all systems are kept separate from other units). With this basis, we then discuss organizational form as a continuum, with isolation and integration as extreme cases.

Options that are Initially Integrated

Knowledge must often be transferred and integrated to realize its full potential (Grant, 1996; Kogut & Zander, 1992; Szulanski, 1996). For example, core competencies refer to knowledge that is leveraged across multiple business units (Prahalad & Hamel, 1990). Accordingly, exercising an option on such assets typically requires that the knowledge must be combined and integrated with other organizational resources.

Furthermore, in some cases, information about the efficacy of a full-scale investment can be assessed only by experimenting with integration (Mosakowski, 1997). For example, a key source of uncertainty might be whether the firm has absorptive capacity to transfer and apply the knowledge (Cohen & Levinthal, 1990). By experimenting with integration, the firm may learn about ease and cost of implementation and, thereby, the value of exercising the option. To use Adner and Levinthal's (2004b) terms, this is another way of saying that uncertainty about the value of exercising the option is endogenous to managerial action. It does not arise from factors external to the firm.

When options are initially integrated, over time there is increasing co-specialization between routines in the new unit and routines in other units. This is part of a process by which internal consistency is maintained while accommodating specialized skills (Doty, Glick, & Huber, 1993). For example, unless the units are isolated from each other (as will be explored), conflicting cultures in different units may seem hypocritical, eroding each value set or converging on one set of values (Schein, 1996). In this way, specialized skills and routines necessitate other co-specialized routines to form a sort of co-specialization machine (Poppo & Zenger, 1998).

Thus, integration creates a category of organizational costs – we call these *disposal costs* – for which there is no comparable category in the analysis of financial options or of real options on tradable assets. These disposal costs may become an important factor in the exercise decision, as a firm that has initially integrated an option may not be able to simply let the option expire, but must bear the organizational costs of disengagement (i.e., in contrast a financial option, for which there is no marginal cost of choosing not to exercise). Thus, interdependent subsystems may create pressure to invest further in co-specialized routines. Like a wave that sweeps through the firm, co-specialization raises the cost of cutting off further investment. Put another way, the disposal costs for letting the option expire may be spread throughout the firm reflecting the interdependencies that develop over time. Thus, allowing an option to expire first requires derailing the co-specialization machine.

The existing real options literature does not focus on these disposal costs or provide guidance in assessing them ex ante. These costs may be very difficult to anticipate when an option is initiated since they depend on ties and routines that evolve over time. Furthermore, estimating and monitoring these costs may not get much easier since they are embedded in routines and social ties. As such, disposal costs consist of breaking these ties, and could turn out to be an important factor in evaluating exercise decisions. These disposal costs should increase with the length of time that the option is held, as the assets become increasingly integrated.

Proposition 1. The more an option on knowledge-based assets is designed to be (or allowed to become) integrated with existing organizational units prior to the exercise decision, the greater will be the disposal costs (organizational costs).

This situation creates a management dilemma that has not been addressed in the real options literature. In cases where the nature of a particular asset requires its initial integration when the option is purchased, firms should expect there to be organizational costs of abandoning this integrated option at the time the exercise decision is considered. At the margin, these organizational costs may influence the exercise decision: it may be desirable to exercise some options that otherwise would be abandoned.

This contrast between the "standard" options analysis and our contribution addressing integrated options and the organizational costs of abandonment is illustrated in Figs. 1(a) and (b). Fig. 1(a) shows the standard analysis. The firm commits a sunk expenditure, the cost of purchasing the option (P). The option allows the firm to limit its loss to P, while giving it the opportunity to capture gains when the expected project income (R) is greater than the exercise price (E). Fig. 1(b) addresses the exercise decision for an integrated option. Here, the loss is not limited to P; rather, the firm is

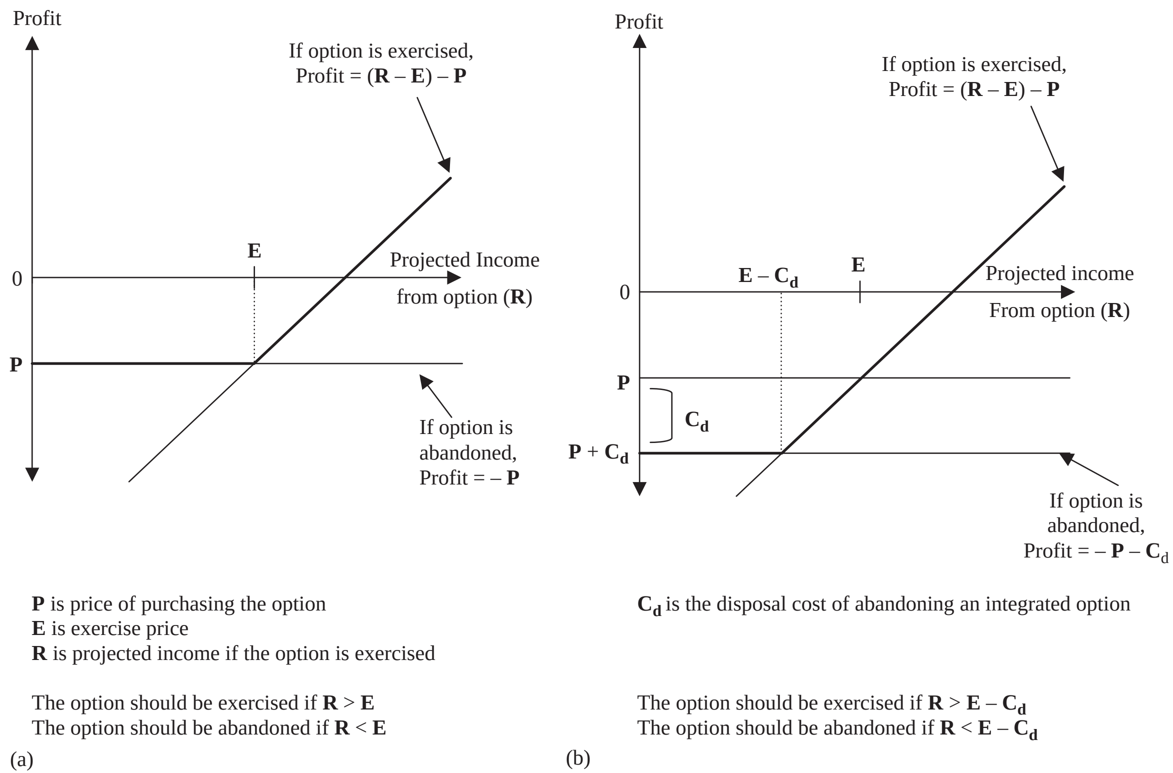


Fig. 1. (a) Standard Options Logic. (b) Abandoning an Integrated Option.

exposed to a total possible loss of $P+C_d$, where C_d represents the organizational costs of abandoning an integrated option.

What is important in this contrast is that C_d is not a sunk cost (in the manner that the cost of purchasing the option is a sunk cost) – C_d can be avoided by exercising the option. Thus, C_d affects the exercise decision, as it represents a cost to abandoning an integrated option. (As noted before, this cost is specific to an integrated option on a knowledge-based asset – such costs are not present for financial options or real options on tangible assets.) The existence of organizational costs of abandonment reduces the projected income necessary to justify exercising the option, from E in the standard case to $E–C_d$ for an integrated option.

Thus, there are situations in which both the decision to purchase the option and the decision to exercise the option may be rational, when viewed in isolation, but the organizational costs of abandonment add a dimension not addressed in the real options literature. It seems that managers should consider the organizational costs of abandonment when choosing to initially integrate options on knowledge-based assets. A firm might be better off not to invest at all rather than purchase an option without an understanding of the disposal costs faced if the option is not exercised.

A Bias to Exercise Options

Beyond the problems created by disposal costs, persistent uncertainty about the value of a full commitment amplifies the role of social capital in exercise decisions. In this case, the effect is to elevate the influence of well-connected managers in the experimental subunit. Through the increased influence of social capital, persistent uncertainty may lead to a systematic bias – beyond the rational consideration of disposal costs – toward exercising options that are initially integrated.

If a great deal of uncertainty about the efficacy of a full-scale investment persists, bias may arise from three key sources: employees in the experimental subunit (i.e., the option), employees in the rest of the firm, and managers who make the exercise decision. First, integration helps managers in the experimental unit use social capital to influence the decision. Research on capital budgeting suggests that when faced with ambiguous signals of project efficacy, the project champion's reputation and ability to influence others serves as a signal of project efficacy (Bower, 1970; Maritan & Alessandri, 2007; Pfeffer & Salancik, 1974). While social capital is often explored as a factor that enhances firm performance as it helps build and transfer knowledge (Leana & Van Buren, 1999; Nahapiet & Ghoshal, 1998), more broadly, it is the "ability to secure benefits through membership in networks and other social structures" (Portes, 1998, p. 8). Here, integration creates social networks for managers in the affected unit, enhancing their influence and helping them push for continued investment. Thus, firms tend to invest in projects sponsored by high-reputation or well-networked managers, while low-reputation managers may be unable to get funding for very promising projects.

Second, employees in other departments and divisions may lobby on their own for continued investment. Aside from the social capital effect cited above, there might be broad support for continued investment to avoid change. As suggested earlier, co-specialization may mean that change would be felt throughout the firm if the option were killed. Thus, managers in other departments may not oppose exercising the option and may even push for further investment.

Finally, individual managers who are directly responsible for the exercise decision might have to sever ties or break implicit contracts with other individuals. An implicit contract is an implied expectation that cannot be fully and formally specified in an explicit contract. Here, the more tightly integrated the units are, the greater will be the expectations of continued transactions. It has been noted that managers are often reluctant to break such contracts, and external forces such as hostile acquisitions are required to sever inefficient implied contracts (Shleifer & Summers, 1988). Ultimately, a new management team may be needed to avoid escalation in such settings (Staw, Barsade, & Koput, 1997).

In this way, persistent uncertainty and integration may interact, creating pressure to escalate commitment even in the face of evidence that further investment is unwise. The structural determinants leading to escalation of commitment[3] mirror the co-specialization machine in the form of "side bets" made that promote continued investment. Staw and Ross (1987, p. 60) wrote:

> Organizations create economic, technical, and political side bets as a project is installed and developed over time. These side bets are incurred to support and implement a given project over its lifespan … [but] are serious considerations in decisions whether to persist or withdraw from a project if it does not appear to be succeeding. … [E]conomic and technical side bets may both inhibit the reexamination of a current course of action as well as contribute added costs to a withdrawal decision.

For example, let us return to 3M, a company praised for fostering creativity and fully backing projects that show merit, was also lauded for business units that were integrated with corporate R&D around a series of knowledge-based core competences, such as adhesives, abrasives, and data storage (Peters & Waterman, 1982). However, recent poor performance has sparked a closer look and stark recommendations to break up the firm (Tatge, 2000). If 3M had killed options that lacked promise all along, they would not have been left with a poorly performing portfolio. Their new CEO, the first outsider to run the firm in 99 years, eliminated 800 of 3M's 1,500 R&D projects to focus on those that had the greatest potential (Merrick, 2001). Apparently, it took a new CEO with few preexisting ties to kill options that had been nurtured far too long.

In sum, the interaction of persistent uncertainty and integration enhances the risk of biased exercise decisions as managers deploy social capital to lobby for funding. Such options create constituencies in favor of continued investment (Drummond, 1994; Staw & Ross, 1987). When a project is institutionalized, its termination requires costly adjustments and clear evidence of failure (Goodman, Bazerman, & Conlon, 1980). While the costly adjustments may be apparent, the clear evidence of failure may be absent or even suppressed.

Proposition 2. For options on knowledge-based assets that have been integrated initially, greater persistent uncertainty about the value of a full-scale investment increases the likelihood of a bias to exercise the option.

The key distinction between Propositions 1 and 2 is whether there is a bias toward continued investment at the exercise decision. Although both propositions address a suboptimal outcome (i.e., overinvestment), the causes differ. Proposition 1 states that a poor outcome may result from a rational (when considered in isolation) exercise decision, given the disposal costs (C_d) arising from integration. The discussion leading to Proposition 2 emphasizes how the initial integration of the asset may result in a bias to exercise the option that may emerge as stakeholders advocate personal agendas.

To some extent the scenarios outlined in these propositions confirm Adner and Levinthal's (2004b) conclusion that escalation is a significant risk. However, note that in the case of Proposition 1, the remedy is simply to estimate and account for the disposal costs (C_d) ex ante; the investment can still be managed as a real option. We now turn to a situation that differs markedly from the one explored by Adner and Levinthal (2004a).

Options that are Initially Isolated

Sometimes, it is not only possible but also desirable to establish options in isolation from other organizational assets. For example, an incompatible culture, routine, or technology may need to be isolated to thrive (Bower &

Christensen, 1995). This, in turn, limits co-specialization and social ties that are associated with the integration process; thereby reducing the bias to exercise options described above. For instance, we proffered the example of how Xerox created a flurry of innovations in their Palo Alto Research Center (PARC). This isolated subunit developed unique skills and routines that flourished apart from the rest of the company.

However, if the required degree of isolation is achieved, the resulting routines may be incompatible with the rest of the firm. In effect, PARC Xerox also illustrates an inability to fully exercise options kept in isolation. While PARC has fostered creativity and innovation, Xerox is famous for failing to take advantage of the options created (e.g., personal computers, networks, and the mouse interface were developed in the 1970s). Here, the innovations did not build on the firm's core knowledge and skills (e.g., marketing and xerography). As a result, management could not exploit the emerging innovations. More recently, Xerox has considered selling all or parts of its "golden goose" to spare it from deep cost cutting efforts (Rae-Dupree, 2001).

The alternative to killing the option may be to eject the rest of the company. GM has tried many times to develop isolated "pockets" that reflect more of a team-based culture – effectively an option on cultural change (e.g., Saturn and NUMMI are prime examples). Generally, the more isolated the unit has been from the rest of the company, the more successful has been the experiment. However, such isolated units are even harder to integrate with the rest of the firm – a key element of exercising the option is to spread the lessons learned to other units. Here, GM could not implement the changes more broadly since they were incompatible with existing routines and values. To exercise the options fully, GM might have to allow the existing divisions to wither while creating new divisions that espouse the desired culture.

Of course, eliminating the core business is a hard decision. Yet, Galunic and Eisenhardt (1996) did find that firms shed old units when they fully commit to new core businesses. Nevertheless, since this type of radical strategic shift often requires new management (Tushman & Romanelli, 1994), exercising such an option may not reflect the ease implied in the literature. As a result, firms may fail to fully exercise options that have been created and isolated.

In general, the longer the firm holds the option, the less compatible isolated routines may become. That is, rather than co-evolving and co-specializing, the isolated unit is likely to develop its own idiosyncratic routines. Indeed, this is the main advantage of skunkworks-style programs – they are not bound by existing routines. However, the firm may ultimately lack the "transformative capacity" to benefit from such options (Garud & Nayyar, 1994).

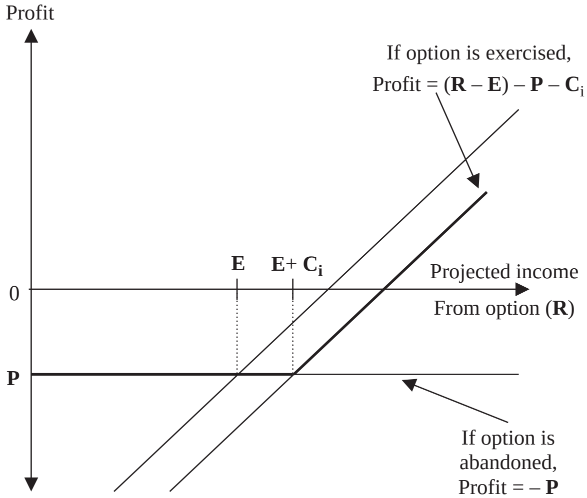
Put another way, there is an organizational component of the exercise price that will tend to creep up over time when options are kept isolated. These costs of integration may be hard to monitor or measure since they manifest themselves in implementation costs, which may not be apparent until the firm has begun exercising the option.

Proposition 3. The more isolated and idiosyncratic an option on knowledge-based assets is allowed to become before the exercise decision, the more organizational costs of integration will inflate the exercise price.

Again, we see a management dilemma that has not been addressed in the real options literature. In cases where the nature of a particular asset requires its initial isolation when the option is purchased, firms should expect there to be organizational costs of integrating this isolated option at the time the exercise decision is considered. At the margin, these organizational costs may influence the exercise decision: it may be desirable to abandon some options that otherwise would be exercised.

Fig. 2 illustrates how these integration costs affect the analysis of real options. Like Fig. 1(a), there are few disposal costs because the isolated unit can be sold or disbanded relatively easily so the firm can limit its loss to P. However, the firm can only capture gains when the expected project income (R) is greater than (E) plus C_i – the sum of the "standard" exercise price (E) and the organizational costs of integrating an isolated option (C_i). Thus, C_i affects the exercise decision, as it represents a cost to exercising an isolated option. (Again, this cost is specific to an isolated option on a knowledge-based asset, as it is generally not present for financial options or real options on tangible assets.) The existence of organizational costs of integration increases the projected income necessary to justify exercising the option, from E in the standard case to $E + C_i$ for an isolated option.

This mirrors our discussion of disposal costs for integrated options in that each decision appears rational when examined separately. However, it seems that managers should consider the organizational costs of integration when choosing to initially isolate options on knowledge-based assets. A firm might be better off not to invest at all rather than purchase an option without an understanding of the organizational costs associated with full integration of a knowledge-based asset. Again, the solution to this dilemma would generally be to try and forecast the integration cost and use it to



$\mathbf{C_i}$ is the cost of integrating an isolated option

The option should be exercised if $\mathbf{R} > \mathbf{E} + \mathbf{C_i}$
The option should be abandoned if $\mathbf{R} < \mathbf{E} + \mathbf{C_i}$

Fig. 2. Exercising an Isolated Option.

inform the purchase decision and the decision of what organizational form the option should take if it is purchased.

A Bias to Kill the Option

Beyond this, biased exercise decisions may result when uncertainty about the value of a full commitment persists, augmenting the effect of social capital. However, unlike the situation for integrated subunits, the elements of social capital work to deter further investment because the experimental subunit is isolated.

This includes the direct influence of the managers in the affected unit, managers in other divisions, and the decision-makers themselves. First, it is likely that the managers in the experimental subunit (i.e., the option) are not well connected, because isolation limits their contacts throughout the firm. In addition to the small number of ties, such managers may have weaker ties because they are not reinforced through day-to-day interaction or routines. Such poorly connected individuals will be in a weak position to influence resource allocations even if the option shows great promise (Pfeffer & Salancik, 1974).

Furthermore, managers in other units are unlikely to rally for investment that requires substantial change. Since the systems have not co-evolved, one might predict that managers will lobby against further investment even in the face of great promise. Indeed, this describes the dynamics at PARC Xerox when so many profound innovations were thwarted.

Finally, the decision-makers themselves may feel less connected to the experimental subunit – creating less of an obligation to preserve implicit contracts. Such managers might not be prone to invest further since their own association with the project is limited. In essence, strong forces are aligned to discourage further investment even if the project shows signs of promise.

Proposition 4. For options on knowledge-based assets that have been isolated initially, greater persistent uncertainty about the value of a full-scale investment increases the likelihood of a bias against exercising the option.

The distinction between Propositions 3 and 4 is similar to the one noted above between Propositions 1 and 2. Proposition 3 describes rational exercise decisions that may lead to suboptimal outcomes. Here, unanticipated costs of integrating an incompatible asset increase the firm's losses (i.e., due to expenditures on the initially isolated option) over what they would have been if a real options heuristic had not been applied. Proposition 4 adds political and social processes that may bias exercise decisions against continued investment in promising assets.

ORGANIZATIONAL PROCESS INNOVATIONS THAT MAY ENABLE REAL OPTIONS

We are presented, then, with two different types of adverse potential outcomes and two distinct underlying problems. Both exercising too many options and failing to exercise promising options are potential outcomes. Thus, the organizational dilemmas associated with a real options approach can lead to opposite outcomes: both type I and type II errors. These outcomes stem from two underlying problems that present management challenges: (1) how to rationally manage organizational disposal and integration costs that may affect exercise decisions, and (2) how to address the risks of bias and opportunism that may be present when making exercise decisions.

Coff and Laverty (2001) attempt to address this from a practitioner's point of view. That is, real options cannot be a valuable tool unless it can be properly applied. However, these dilemmas also offer fruitful avenues for further research as the solutions are of theoretical interest in their own right (e.g., organizational form, timing of exercise decisions, process interventions, monitoring, and option portfolio management). In this section, we begin to flesh out some implications.

Managing and Mitigating Organizational Costs

The first problem, underscored in Propositions 1 and 3, involves the estimation and management of integration costs and disposal costs that may influence (or even hijack) exercise decisions. Here, we describe two strategies for managing organizational costs to minimize their effects on the exercise decision: (1) manage the organizational form that the option takes, and (2) make exercise decisions as early as possible to avoid the accumulation of organizational costs.

Managing Organizational Form to Balance Costs

The previous discussion has suggested that two opposing outcomes that may result from extremes on what can be thought of as an integration-isolation continuum. While examining the extremes helps to illuminate the disparate outcomes that are possible, in reality, there are many points in between that represent intermediate or hybrid organizational forms. In practice, these may be the most promising points from which to manage the integration and disposal costs.

Thus, the first task managers must face when establishing a real option is the degree of integration with other assets required to evaluate whether the option should be exercised. Unlike our previous discussion, this is not a discrete decision of whether to integrate or isolate the option. Rather it is a decision of how to design coordinating structures that help evaluate the option's efficacy while controlling integration and disposal costs that may be incurred when the exercise decision must be made.

The organizational theory and design literature provides a lucid discussion of such mechanisms. For example, Thompson (1967) describes different types of interdependencies that may exist between organizational subunits. Daft (2001) elaborates by describing a continuum of horizontal coordination mechanisms ordered by the degree of coordination or integration required: routines linked by paperwork, ad hoc direct contact, liaison roles, task forces, full-time integrators, and cross functional teams. The first few alternatives (e.g., paperwork or ad hoc direct contact) provide a small degree of integration while minimizing potential disposal costs. The later alternatives (e.g., full-time integrators and teams) minimize integration costs should an option be exercised but may have substantially higher disposal costs if the option is to be killed.

Organizational form alternatives allow managers to control where on the integration-isolation continuum an option is established and nurtured. There are two key challenges for managers with respect to this decision. First, they must identify how any particular balance between integration and isolation provides benefits in the form of reliable information about the value of exercising the option. Second, they must identify the potential organizational costs associated with any particular balance between integration and isolation. In principle, it is possible in this manner to identify an optimal organizational form. In practice, such judgments will almost always have to be made using qualitative data. Nevertheless, existing theory does not even suggest that these issues must be addressed.

Managing Time to Minimize Organizational Costs

Since the time frame for exercising a real option is rarely specified, managers have considerable discretion about when to make such decisions. While some latitude in scheduling may be beneficial, the ambiguity may push managers to delay too long. Indeed, this is an important part of Adner and Levinthal's (2004b) argument. However, managers will also be aware that the cost of postponing is complicated by important strategic considerations. For example, where first mover advantages are possible, the benefits of waiting for uncertainty to dissipate may be overwhelmed by the cost of moving too slowly (Lint & Pennings, 1999). Thus, in an organizational setting there are conflicting time pressures on real options – both to delay exercise decisions and to move them forward.

Our discussion adds to the importance to managing the time dimension since the organizational costs (both of integration and disposal) tend to increase with the length of time that an option is held. Over time, integrated units tend to become more integrated. Social ties become stronger and more widespread. Formal and informal organizational routines develop so as to increase the tightness of coupling over time. Thus, disposal costs for options that have been initially integrated will increase the longer the option is held. The opposite may be true for isolated options where idiosyncratic routines develop over time. In the absence of integration, the units will tend to diverge and become less compatible over time. Routines fail to co-evolve in a complementary and cohesive fashion. Over the time an initially isolated option is held, integration costs will comprise an increasingly large portion of the exercise price.

As such, an awareness of the organizational costs should aid managers in timing exercise decisions. Timing is difficult because there will always be a feeling that if they wait longer there will be better information. However, both organizational costs and strategic considerations suggest earlier, rather than later, exercise decisions. Unlike financial options, it is important for managers to understand that uncertainty about the efficacy of exercising a real option may never dissipate. Thus, the value of delay – in terms of better information – must be evaluated carefully, since delay increases organizational costs and may result in missed opportunities.

Process Interventions to Correct for Bias and Agency Costs

The agency costs and risk of bias that underlie Propositions 2 and 4 present another sort of dilemma for real options theory. Even if the organizational costs could be estimated accurately and balanced when the option is initialized, individuals may have incentives to distort the costs and information about the efficacy of exercising the option. This dilemma is enabled by persistent uncertainty, which allows reputational signals and social capital to inject bias into the decision-making process. Put another way, in the absence of persistent uncertainty, decision-makers would be in a better position to consider organizational costs rationally and avoid systematic bias.

However, we suggest that such agency costs may be addressed, at least to some extent, through process and structural interventions that affect the power structure present in the exercise decision. Thus, to address this problem, managers must ultimately design structures and processes that balance the power structure to minimize the risks of overinvesting and missing key opportunities. Research should therefore focus on structural and process innovations to find out if they can mitigate the problems we describe.

Remedies that Address Both Types of Bias

We begin with interventions that simultaneously address the risk of escalation and the risk of killing promising options. In this sense, these represent general strategies to mitigate organizational bias in exercise decisions. These include managing organizational form and monitoring exercise decisions.

Organizational Form and the Risk of Bias. We have already discussed the relationship between organizational form and organizational costs and the

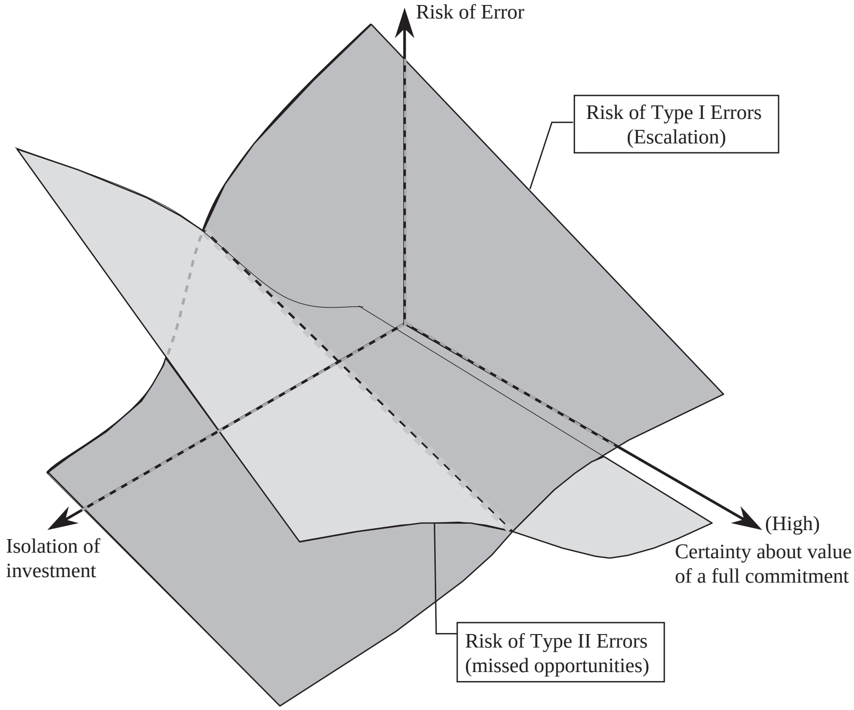


Fig. 3. Competing Risks of Type I and Type II Errors.

relationship between persistent uncertainty and biased exercise decisions. Along these lines, Fig. 3 displays the risks of type I and II errors as functions of a continuous integration-isolation dimension and the degree of certainty at the time of the exercise decision. The dark surface shows that the risk of exercising an option that should be abandoned increases with integration and uncertainty. The light surface shows that the risk of abandoning an option that should be exercised increases with isolation and uncertainty.

The intersection of the two surfaces is a line that represents equal risks of type I and type II errors. Note that for any level of uncertainty, there is a single point on the integration-isolation dimension that achieves this equality. While it is tempting to say that this "tightrope" captures the optimal balance between integration and isolation, this is only true if the costs of type I and type II errors are identical, which may not be the case. For example, sometimes the cost of killing a promising project may not be as high as the cost of a high-profile failure (i.e., betting the company). Furthermore, an organization may have a tendency toward one type of error and need to overcompensate to achieve balance.

In this way, the organizational form that an option takes influences the power structure in place at the exercise decision. An intermediate or balanced degree of integration may limit the ability of any one stakeholder to obtain funding based on social ties alone. Accordingly, options may be created with a structure that grants project champions some social capital but not overwhelming access to and influence over the decision-maker. This implies a balanced structure at neither end of the integration-isolation continuum – a point that may also balance the tradeoffs of integration and disposal costs.

Thus, in designing an option that must be isolated in order to thrive, a firm might create liaison roles and coordination mechanisms so the project champion gets to know managers in the parent company. Similarly, if an option must be integrated, steps might be taken to isolate the decision-maker from the project champion's influence. This might include reviews of such decisions at a higher level or impartial external reviews (such as a scientific advisory board). In this sense, managing the organizational form carefully may help address two types of dilemmas that may plague the application of real options heuristics to knowledge-based assets.

Monitoring of Exercise Decisions. A traditional agency solution is to increase monitoring of the agents (Jensen & Meckling, 1976). Thus, monitoring is a second coping strategy that may address both the risk of escalation and killing promising options. Here, firms may be able to reduce the risk of bias by adjusting the process by which exercise decisions are conducted to review and monitor more carefully. For example, one response to the risk of overinvestment is to require a rigorous external review of exercise decisions from experts who have no interest in the outcome. Along these lines, cutting-edge technology firms often have scientific advisory boards to review their R&D portfolios. While these often serve to grant status and legitimacy to the firms (by involving eminent scholars), the review process may also provide useful information and an assessment unbiased by the influence of social capital.

This is similar to the process for making tenure decisions at major research universities. The academic model may be instructive since universities formally and informally specify that they are "buying an option" on junior faculty. It is clear at the outset that there is limited commitment. Rigorous external review provides important information for the "exercise" decision and limits the extent to which the candidate can influence decision-makers directly. Furthermore, the decision is reviewed at a higher level in the university at which the candidate rarely would have any direct social ties that would bias the decision process.

While we are cautious in suggesting that businesses emulate universities in the matter of tenure, the consequences of the process deserve attention. First, a natural consequence is that junior faculty may limit institution-specific investments, such as those required to build new programs, which will turn out to be worthless if the option is not exercised. Outside of the university setting, failure to invest in firm-specific knowledge may reduce the potential for competitive advantage and thus the value of the option. Second, while junior faculty develop social capital that may allow them to influence exercise decisions, the external review and the review at the university level limit the risk of escalation. Third, the tenure system seems to treat type I error (overinvestment) as a more critical concern than type II error ("killing" a promising "project"). In universities, this may be the case, given that tenure creates colleagues for life. However, this may or may not be true in business settings where the cost of killing a promising project may be substantial as well.

Monitoring and external reviews may also reduce the risk of killing a promising option. For example, if an external scientific advisory board were to review a set of projects, their opinion is unlikely to depend very much on the degree to which each project has been integrated into the firm. It may also be possible to push the exercise decision high enough into an internal hierarchy that the decision-maker has few direct ties to the various project champions (like a university-level review of tenure decisions).

Interventions Specific to One Form of Bias

Some remedies may be more suited to mitigate either the risk of escalation or the risk of killing a promising option. For example, in order to counter the risk of escalation, the firm might construct its portfolio of options to create a credible commitment to kill options. In contrast, if more concern is focused on missed opportunities, interventions might limit or even eliminate the role that reputation or social capital plays altogether. We briefly describe these below to illustrate the potential for innovations in structure and process to reduce the risk of certain types of errors.

Portfolios that Create Credible Commitment. There is an emerging literature that explores interdependencies that develop between options and other resources (Anand, Oriani, & Vassolo, 2007; Vassolo, Anand, & Folta, 2004).

Similar logic applies to all such interdependencies, whether among options or between options and other assets. Where multiple options are complementary and initially integrated, the pressure to exercise will be more intense as all of the project champions lobby in concert – without regard to the efficacy of exercising the options. This would tend to exacerbate the risk of escalation.

In contrast, when options compete (e.g., the firm is hedging on a technological standard), champions for opposing options may be expected to lobby against exercising any option other than their own. Organizationally, this may reduce the risk of escalation by signaling credible commitment to kill all but one of the options. On the other hand, if the firm sees a portfolio of competing options as representing switching opportunities, this commitment may be lost (Oriani, 2007). This suggests that the problems identified here might have implications for decisions about portfolios of options, as opposed to treating each option independently. Research on portfolios of real options might reveal implications for interdependencies among options as well as a way to mitigate the risk of a bias to escalate commitment.

Group Process Interventions to Limit the Role of Social Capital. In the context of an isolated option, we have a setting in which the project champion is likely to have relatively less social capital from which to influence the exercise decision. Here the problem is how to get decision-makers to recognize a sound project even if its proponent is not powerful and well connected.

Here, group process interventions may address this problem by bringing out information and opinions separately from their source. For example, group decision-making approaches such as the Delphi method or Nominal Group Technique bring ideas to the forefront while placing less emphasis on their proponents. Delphi involves eliciting responses from a group and summarizing them without reference to who made what comment. In this way, the group reviews inputs from all members and is more likely to entertain and reach consensus on ideas that may emerge from low-status individuals (Felsenthal & Fuchs, 1976).

In sum, a real options heuristic may offer a vital innovation for making strategic investments under great uncertainty. However, it may also set in motion structural and political processes that threaten to undermine its effectiveness. We have argued that the real options literature is incomplete with regard to these organizational theory and strategy process issues. The continued integration of the literatures on real options, organizational theory, and strategy process may ultimately produce solutions to a key dilemma – how to invest in knowledge-based assets.

CONCLUSION

The premise of this article is that real options logic can be applied to investments in knowledge-based assets. We began by observing that Adner and Levinthal (2004b) cast some doubt on how useful real options might be for this important category of strategic investments. We strongly share their concern for organizational processes, but we believe that the organizational form an option takes and various managerial process interventions may offer tools that will enhance the usefulness of real options even in this context.

We have offered an analysis of how organizational form affects decisions to exercise options on knowledge-based assets – a problem that is just beginning to receive serious inquiry. Our analysis suggests that the real options literature is incomplete without attention to structure and processes in order to understand and predict its ultimate impact in organizations. This line of inquiry, then, helps to identify new avenues to advance theory in real options and the resource-based view – topics to which we now turn.

Achieving the Promise of Real Options

The enthusiasm for real options heuristics arises from the potential to promote critical initial investments in both tangible and intangible organizational assets in the face of uncertainty (Kogut & Kulatilaka, 2001). However, this potential can only be realized if firms make effective exercise decisions, which, in turn, depend on the structures and processes within which exercise decisions are embedded. The risks of overinvestment (exercising too many options) or underinvestment (missing opportunities by failing to exercise options) are challenges to the promise of a real options approach. We have identified some interventions in organizational structure and decision-making process that may mitigate these problems. Additional research to assess and develop such interventions by integrating real options theory with organizational theory will help to achieve the full potential of the real options approach.

As firms gain more experience with real options, researchers will have more opportunities for empirical work that addresses how firms respond to and manage the organizational costs we have described. Field studies could examine how framing investments as options affects processes and outcomes. Good examples for such research include Bower's (1970) study of capital budgeting and (Burgelman, 1983; Garud & Van De Ven, 1992) studies of managing new venture divisions. Additional field research might expand on these themes first by studying investments in knowledge-based assets, and second by exploring organizational costs and how they influence exercise decisions in a business context.

There is also an opportunity to examine the impact of organizational costs on the cognition of options. Existing research by Bowman and Hurry (1993) and Slater, Reddy, and Zwirlein (1998), among others, suggests that managers consider option value intuitively. To what extent might this also apply to organizational costs that will affect exercise decisions? Do managers use reliable heuristics for the dilemmas we have described? This might be the subject of a laboratory or a survey-based research exploring cognitive aspects of these organizational costs.

Real Options and Knowledge-Based Assets

We have focused explicitly on knowledge-based assets in a corporate context where knowledge must be leveraged and transferred to exercise such an option. Here, the development process for knowledge-based assets involves experience, mid-course correction, and the discovery of opportunities. Prahalad and Hamel (1990, p. 83) observed, ''Philips could not have imagined all the products that would be spawned by its optical media competence, nor could JVC have anticipated miniature camcorders when it first began exploring videotape technologies.'' Thus, investing in knowledge-based assets is an ideal application for real options.

As we have described, the position taken by Adner and Levinthal (2004b) is based upon a focus only on the problem of escalation and has not considered alternate organizational forms that an option might take. Accordingly, we believe that options may be quite useful even for options that involve endogenous uncertainty – if they are managed properly. In actuality, the efficacy of real options on knowledge-based assets depends upon an organization's structure and processes. The fundamental task is to recognize the nature of knowledge-based assets and the path-dependent processes generated by real options in organizations. Our analysis describes how organizational costs and potential biases in decision processes can be analyzed as the firm chooses a course of action regarding a particular investment. Organizational form is a crucial strategic decision. Our approach proposes the benefits of hybrid forms, in between the extremes of integration and isolation, and process innovations.

An extension of our work in this area might be to study situations that do not involve leveraging knowledge across the firm. As we have noted, in most situations knowledge must be transferred and integrated with complementary assets in order to achieve its maximum potential value (Kogut & Zander, 1992). In fact, an implicit boundary condition on this discussion has been knowledge-based assets that must be transferred and leveraged to be exercised. For example, if developing a knowledge-based asset were part of a business unit strategy rather than a corporate strategy, the range of knowledge transfer and integration would be more limited. In this case, the total integration costs and total disposal costs would be less. However, even for a business unit strategy, some initial integration (within a business unit) may be needed to assess the option. While this may be less extensive than that required for core competencies (knowledge leveraged across business units), it would create organizational disposal costs that affect the exercise decision. Similarly, if such an option is initially isolated from the business unit, it may still develop incompatible routines that raise the exercise price. This is fertile ground for additional theory building and empirical research at the business unit level.

Real Options and the Resource-Based View

Our analysis has also contributed to theory development with respect to the resource-based view by exploring the embedded investment dilemmas. At the core of the resource-based view lies the question of how firms acquire strategic assets under great uncertainty for less than their ultimate value in use (Barney, 2001). For example, some firms may have superior information about a given resource (Barney, 1986). Similarly, value may be created through unique complementarities among assets accumulated over time (Dierickx & Cool, 1989).

Thus, at the core of the resource-based view, lies a thorny investment dilemma. In part, this is why the spread of real options logic is at once both promising and challenging. For example, firms are prone to both overinvestment and underinvestment without real options. Are the dilemmas associated with a real options heuristic more or less serious than those of alternatives? Despite the challenges we discuss, it still may be the best available approach. This question may only be answered through further integration of the organizational theory literature to study the specific application of a real options approach to investments in strategic assets.

Indeed, the challenges we identify raise another issue that may spark interest in real options. A real options approach may incur substantial costs when implemented in maladapted firms. If real options – as an approach to making strategic investments under uncertainty – were equally available to all firms, it could not explain persistent interfirm differences. Our analysis suggests that what is critical is not the ''concept'' and basic logic of real options, but whether firms have the ability to identify and implement an organizational form and processes that balance organizational costs. The ability to utilize a real options heuristic effectively may be an important part of a resource picking capability (see Makadok, 2001) that is valuable, rare, and unavailable to most firms. If future research confirms that a real options heuristic requires rare complementary capabilities, its role in resource-based theory may prove to be substantial.

NOTES

1. In financial options models, uncertainty is the variance in the underlying asset's value. However, if the market for the underlying assets is incomplete, the variance is almost impossible to determine. Consistent with how McGrath (1997) and others address uncertainty, this is ''persistent uncertainty'' – the degree to which the value of the underlying asset is unknown – as opposed to the variance concept used in financial models.

2. We use 3M, Xerox, and others as examples of firms that implicitly apply real options heuristics – making exploratory investments with the intention of fully funding only those with great promise. While their strategies predate the real options literature, they resemble what would now be considered a real options heuristic. This approach is increasingly recommended as limitations to quantitative methods emerge (Bowman & Moskowitz, 2001).

3. Note that this article focuses on the structural or organizational antecedents to escalation rather than the psychological attributes associated with a given decision-maker's tendencies to escalate commitment.

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REAL OPTIONS AND RESOURCE REALLOCATION PROCESSES

Ron Adner

ABSTRACT

This article considers real options approaches through the lens of firm's resource reallocation processes. It explores some potential drivers and consequences of mismatches between initial resource allocation logics and subsequent reallocation realities, highlighting a process of rational escalation in the presence of sunk costs. It also presents a new perspective on the traditional stage-gate process, and considers some recent empirical evidence on the efficiency of resource reallocation processes in organizations.

Decision making using a real options lens can be an important guide for resource allocation in organizations. This guide, however, makes some key assumptions about the nature of subsequent resource reallocation processes in the organization. This article considers some potential drivers and consequences of mismatches between initial resource allocation logics and subsequent reallocation realities, highlighting a process of rational escalation in the presence of sunk costs. It also presents a new perspective on the traditional stage-gate process, and considers some recent empirical evidence on the efficiency of resource reallocation processes in organizations.

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Whether advocated in its strong form as a core valuation tool, or in its more moderate forms as a ranking tool, a heuristic or a metaphor, the appeal of real options thinking lies in its promise of structuring decision making under uncertainty. Because it explicitly incorporates the ability of decision makers to make sequential commitments to a course of action, and to benefit from updated information as this sequence unfolds, real options thinking has been held out as an appealing lens through which to view the content and process of strategy making. The appropriate application of real options theory to the strategy field, however, has been a subject of some debate (e.g., Adner & Levinthal, 2004a, 2004b; Coff & Laverty, 2001).

MATCHING RESOURCE ALLOCATION LOGICS WITH RESOURCE REALLOCATION DECISIONS

At its core, real options thinking presents an approach to managing the resource allocation process. An attractive feature of the real options perspective is its seeming correspondence to the resource allocation process at many firms. In many organizations, the process of winnowing down investment candidates takes place over multiple rounds, with the formal expectation that selection criteria become stricter, and that resource commitments become larger, in each subsequent round. This stage-gate process, often represented as a filtering funnel in which proposals pass through a series of increasingly challenging screens, is a standard feature of multitudes of corporate presentations (Fig. 1a).

It is important to remember, however, that the resource allocation process has two sides: the initial allocation of resources to initiatives, as well as the subsequent *reallocation* of resources away from initiatives. Hence, a more appropriate representation of the resource allocation process may therefore be one, as in Fig. 1b, which explicitly incorporates the reallocation

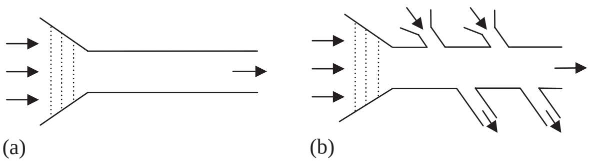

Fig. 1. Two Alternative Representations of the Stage-Gate Process for Resource Allocation in Organizations.

philosophy for the firms – the modes by which project can exit from the organization's activity set.

As noted in Adner and Levinthal (2004a, 2004b), sequential decision making per se is a general property of path dependent processes; therefore, it is the correspondence between initial resource allocation justifications and subsequent reallocation decisions that is the litmus test for the use of real options in real organizations. At the core of the Adner and Levinthal critique of the use of real options in strategy is a concern with the consistency between the logics and expectations that underpin a firm's initial resource allocation decisions, and the organizational realities that govern firm's subsequent resource reallocation decisions. Table 1 characterizes the possible combinations. The debate on the applicability of real options hinges on whether organizations are able to discipline themselves to reside in the lower right quadrant, and resist drifting to the lower left.

In assessing the applicability of real options to strategy, it is important to separate arguments about the *possibility* that real options logic can be correctly applied to inform strategy decision making, from arguments about the *probability* that the assumptions that underlie this logic will hold in real organizations.

An assumption of particular interest regards the consequence for an initiative when target goals are not met. Such negative information can lead to two different courses of subsequent investment. One possibility is that the cause of the negative outcome is explored and steps are taken to overcome the obstacle. This first type of flexibility is what many would expect of successful organizations – giving up in the face of adversity seems contrary

Table 1. Correspondence Between Initial Resource Allocation Logic and Subsequent Resource Reallocation Process.

	Subsequent Reallocation Process	
	Persistence in search	Disciplined pruning of portfolio activities
Initial resource allocation logic		
High commitment investment	Coherent decisions and actions	Mismatched
Low commitment investment	Mismatched (flexible exploration, not consistent with real options logic used in initial project justification)	Coherent decisions and actions

to our image of what good managers should do. A second possibility is that, since the project failed to meet the targets on which its continuation had been premised, the project is terminated, thereby freeing up resources to be used elsewhere. It is this second type of flexibility that is implied by disciplined investment guidelines that underlies a real options perspective.

If one takes as a null hypothesis that organizations are subject to path dependence, then it is only by confronting the question of resource reallocation we can understand the descriptive value of using a real options lens to understand organizational decisions.

RATIONAL ESCALATION IN THE PRESENCE OF SUNK COSTS

A rich literature in psychology and organizational behavior has explored underlying drivers that act against the ability of individuals and of organizations to efficiently reallocate resources away from existing initiatives. The psychological factors that act to support the escalation of commitment to a course of action even in the face of negative information are numerous (cf., Staw, 1976, 1981; Staw & Ross, 1978). Of particular relevance for real options, is the relationship between the way in which information is presented and the way in which it is processed. When negative information does not arrive all at once, but rather is sequenced over time (as is generally the case in any path dependent exploration activity) and when the overall stream of negative information is occasionally interrupted by promising developments, managers have a more difficult time convincing themselves that the course of action which they are pursuing is a failing one, and not worthy of additional attempts to improve the situation.

In such settings, managers are often argued to be particularly vulnerable to "self-justification bias." Alternatively, managers in such situations are often accused of succumbing to the "sunk cost fallacy," throwing away good money after bad.

This is a possible misattribution. In fact, the opposite logic may be at play – a manager who understands that sunk costs are sunk, and that they should not affect future decision making will have a very difficult time justifying terminating a project in which additional investment might lead to success (that is, a project whose outcomes are at least partially endogenous to the manager's investments and actions). Consider the following scenario: An R&D project is initiated with the expectation of a sufficient payoff 3 years hence. At the end of 3 years of investment, the project is not yet a success.

Hopes are as high as ever, but an additional 2 years of investment will be required to achieve the initial expected payoff. One perspective on the problem would argue that the payoff was worth 3 years of investment and no more; therefore, it is time to abandon the project and move on. Another perspective, however, would argue that it is precisely because the payoff is worth 3 years of investment that investment should continue – the initial investment is now sunk, and so should not enter the calculation. Since the payoff is now available with only 2 years of investment, investing in the initiative is even more attractive than when it required 3 years of investment. We can imagine how this logic can continue to justify additional investment long into the future.

In settings characterized by an ''impossibility of proving failure,'' (Adner & Levinthal, 2004a) in which managers can affect outcomes through additional resource investments, the potential for such rational escalation looms large. When the cost of incremental search is low relative to the initial costs of the project, to the cost of terminating a project, or to the cost initiating a new project, there is likely to be an economic rationale for continuing investment. This rational, when operating on an entire portfolio, will tend to shift organizations from the lower right quadrant to the lower left quadrant of Table 1.

EXTERNALLY VS. INTERNALLY GENERATED OPTIONS

Note that this discussion has focused on an individual manager's perspective on the resource reallocation choice. Expanding the treatment to consider the potential impact of social psychology, organizational politics, or economic agency would uncover additional drivers that may further reduce the likelihood that initiatives will be terminated in a manner consistent with the assumptions that were in place at the time of their initiation. Organizational design will clearly play a role in the extent to which organizations will drift to escalation.

While this discussion has focused on the challenges of effective project termination, organizations can also fail on the side of overzealous termination indeed, Coff and Laverty (2007) examine the role that organization design can play in leading firm to under invest in real options and terminate opportunities prematurely.

Isolating initiatives within the organizations makes them easier to shut down. In the extreme, running initiatives entirely outside of the organization should make the management of over commitment even easier. This is essentially the case of joint ventures. As Reuer and Tong (2007) note, however, if opportunities are to be sourced outside the firm, they are necessarily sourced at a price. The question then become, whether the value of the initiative will be captured by the acquiring firm, or by the factor market from which the initiative is acquired. This suggests a tradeoff between ease of termination and potential for value capture net of acquisition price, where internally sourced initiatives offer higher expected value capture net of acquisition cost, but at the price of greater escalation risk; while externally sourced initiatives offer a clearer path to de-escalation but at the price of higher acquisition costs.

It should be noted, however, that empirical examinations of the efficiency with which firms are able to terminate even externally sourced opportunities paints a relatively unflattering picture of the discipline with which firms approach the pruning of their portfolios. Reuer and Leiblein (2000), for example, studied the effectiveness with which firms were able to use joint ventures to reduce their downside risk. They found however, for both domestic and international joint ventures, the opposite to be the case – that joint ventures actually served to increase firm's downside risk. Tong, Reuer, and Peng (2008) examine a sample of international joint ventures and find that the likelihood that they impact firm's growth option value as predicted by theory is contingent on the structure of the IJV, where initiatives where the firm has a large equity stake, are core to the firm's main line of business, or are located in developed economies are unlikely to be managed in a way that exploits the flexibility inherent in real options thinking.

Most directly, in a recent working paper, Cuypers and Martin (2006) specifically examine the effectiveness of endogenous uncertainty resolution on the likelihood that firms manage their joint ventures in way that are consistent with real options predictions. Their findings support the arguments put forward in Adner and Levinthal (2004a, 2004b) that endogenous uncertainty resolution degrades the discipline with which firms adhere to a real options logic.

SOME ADDITIONAL EMPIRICAL OBSERVATIONS

To be clear – this article is not questioning whether firms can terminate initiatives. The question is whether the abandonment processes that we observe in firms are efficient – in the post mortem, does it appear to be the case the organization was able to stick to its initial, planned thresholds for decisions, or did it shift into a mode of managing by exception, succumbing to the temptation to keep projects alive because "success is just around the corner." It is this distinction which allows us to consider the probability (rather than the possibility) that real options are at play in real organizations.

The bulk of empirical investigations in the real options literature have attempted to show that sequential decision making is a better descriptor of organizational behavior than is the all-or-nothing commitment structure implied by traditional valuation techniques such as discounted cash flow analysis. While such analyses offer compelling evidence that sequential decision making is a better characterization of investment processes, they shed little light on the sub-processes that underlie sequential decision making in organizations. They are therefore ill-suited to distinguishing between the rational, consistent, and disciplined approach to sequential decisions implied by a real options perspective, and the more fluid, chaotic, and opportunistic non-approach implied by path dependence.

Distinguishing between these competing perspectives requires a finer grained examination of resource reallocation processes. Those studies that have pursued more detailed investigations of the resource reallocation processes present a picture that is as best mixed, and at worst depressing. I highlight a subset of findings here:

The innovation and learning literatures are replete with examples and explanations of organizational inertia. Sull's work in the automobile tire industry is particularly interesting in this regard (Sull, 1997, 2005). Exploring the contextual forces that prevented established tire manufacturers from reallocating resources away from their traditional bias and belted-bias tires towards the production of radial tire, this works sheds light on the complex stakeholder relationships that propel organizations along existing trajectories.

While significant inertia may have been expected to characterize broad shifts in corporate strategy, it may be somewhat more surprising to encounter it in the context of corporate venture units, which are specifically designed to efficiently and aggressively screen projects as they move through the funneling process. In a their detailed study of the corporate venturing arm of a large European electronics manufacturer, Keil, McGrath, and Tukiainen (2005) examine the management of a population of 37 ventures through a selection process involving four formal stage-gates. While the firms own expectations were for significant increases in selectiveness across stages, commensurate with the significant increases in resource commitments which progress through each gate represented, Keil et al. report that of the 37 initiated projects, 65% of the population (23 projects) passed on to the second stage of investment, that of these 61% passed on to the third stage (14 projects), and that of these, 100% were either still in the pipeline or already integrated into the firm at the time they ended their observation. While the terminations per se may or may not be related to failure, the observation of termination rates is particularly interesting because it suggests that, at least in this case, the firm's own initial expectations for selectivity at its own stage-gates were dramatically out of line with its subsequent reallocation decisions.

The importance and prevalence of social networks among the project initiators and project evaluators in corporate venturing settings might be seen as an explanation for the slippage between initial expectations for strict selection and a de facto munificence in resource reallocation decisions. The venture capital industry, in contrast, should represent a best case setting for disciplined exit from initial investment commitments. The industry's structure, with explicit funding rounds, and with (nominally) dispassionate partners who have a fiduciary responsibility to maximize returns for their own investors as well as high powered incentives to assure that their interests are aligned with investors rather than with portfolio companies, seems ideally suited to the task. In this regard, however, Guler's (2005, 2007) recent studies of investment patterns in the venture capital industry give some reason for pause. She finds statistical evidence, supported by qualitative field work, that venture capital investors escalate their commitment to portfolio company investments, and ignore incoming information in sequential investment rounds. She also finds that those firms that are more disciplined in their ability to terminate their commitments to portfolio companies have higher performing portfolios. Since these funds are managed by general partners who are in fact agents of limited partners, it does raise the additional question of the degree to which inefficiency in exist is being driven by decision biases compared to more traditional agency problems. In either case, however, it highlights the challenges of efficient exit on which the real options approach is predicated.

The indicative findings from the corporate and private venture capital settings are consistent with the results of studies of the investment patterns of stock market investors. As a class of decision makers, individual investors are making among the most reversible commitments possible, buying and selling shares in a very liquid market. They are also among the least able to influence the outcomes of their investments. Despite this, a number of studies in the finance field show that investors display over commitment to the shares of stock that they own (cf., Shefrin & Statman, 1984; Odean, 1998). Shapira and Venezia (2001) report similar findings for professional investors.

EMPIRICAL BASELINES AND STANDARDS OF EVIDENCE

If we are to really understand the use of real options logic in organizations, it seems imperative that we develop a better understanding of the resource reallocation process. What actually happens within the project-filtering funnel? What is the relative balance between "flexibility as redirection of activity" and "flexibility as reassignment of resources"? How closely does reality approximate the ideal that underlies visions of real options? More importantly, how closely does the reality within an organization approximate the organization's own assumptions about its behaviors. It is only with a better sense for baseline approaches to managing sequential decision making in organizations that we can begin to make crisper distinctions between unstructured evolution constrained by path dependence, and structured progress guided by a real options logic.

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WHY INVEST IN FIRM-SPECIFIC HUMAN CAPITAL? A REAL OPTIONS VIEW OF EMPLOYMENT CONTRACTS

Todd Fister and Anju Seth

ABSTRACT

This paper complements previous research on investment in firm-specific human capital by applying real options analysis. Our framework suggests that the parties receive valuable options to exit the contract when information becomes revealed in the future, but these options may be more valuable for one party than the other. Companies and workers attempt to reduce the value of the options through contractual mechanisms that either shift wealth to the party granting the option or prevent the option from being exercised. In both cases, the mechanisms cause the parties to invest in firm-specific capital, resulting in higher output and higher wages.

"Contracts are inherently bilateral negotiations between partners that are disciplined from external opportunities, making analysis of the labor market more akin to the marriage market than to the bourse" (Rosen, 1985, p. 1145).

"Many well-known relational contracts have come under substantial stress (and sometimes failed) when the world has changed important parameters,

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such as the expected profit for the firm. For example, for several decades IBM made a "no layoffs" pledge to its employees. This was not a formal contract, enforceable by a court, but it was part of "the deal" at IBM: a shared understanding between the firm and its employees about how employment would proceed.... Eventually, IBM abandoned the policy" (Gibbons, 1998, p. 122).

In less than 20 years, IBM has transitioned from the blue-chip American employer to a company that hires more outsourced, international, and flexible employees than traditional workers, that has no pension plan, and that no longer hints at lifetime employment (Jones, 2005; NYT, 2006). At the same time, General Motors, the premier employer of the 1960s and 1970s, has offered even its factory workers large one-time payments to stop working and to separate from the company. These payments go up to $140,000 for low-tenure employees (Maynard, 2006). The changing nature of employment relationships has prompted a relatively new stream of research in employee governance. Companies would not invest capital in assets that do not carry property rights, specifically the rights to make decisions regarding the use and sale of the assets and to receive profit from such decisions. Yet, employees seem to make these investments all the time. Workers invest in firm-specific assets that generate future cash flows for the firm, but they receive no decision or property rights to control these investments (Blair, 1995, 1996, 1999; Blair & Kochan, 2000).

Like marriage, the ex ante assumptions underlying the labor contract are mutually understood rather than explicitly stated, and an ex post separation is costly. Firm-initiated layoffs force workers to sell their investments in firm-specific human capital at a price of zero, which obviously creates downside risk that most investors would avoid (Fallick, 1996). The magnitude of employee losses is large, with an average present value of $115,000 for workers with 6 or more years of firm tenure and $155,000 for workers with 11–12 years of firm tenure (Schultze, 2000). The percentage wage loss after a layoff is estimated to range from 14 to 36%, a meaningful loss in a country where the savings rate hovers near zero (Kletzer, 1998).

Why do employees invest in firm-specific human capital despite the lack of decision and property rights over the investment and the risk of losing the investment? Our paper uses a real options theoretical framework to address this puzzle. A considerable body of prior work has used the real options lens to generate insights into the firm's decision to invest physical capital in settings where the economic value of the project is characterized by ex ante uncertainty, e.g., R&D, expansion, and entry. More recent work has also examined the implications of the framework for investments of physical capital under conditions of complementarity between two parties, wherein each possesses only a part of the necessary assets or skills for the new project. These projects thereby entail inter-firm contractual arrangements such as joint ventures (e.g., Chi & McGuire, 1996) and technology licensing agreements (Ziedonis, 2004). The real options view has also been used to shed light on the choice of optimal contract structure for realizing the benefits of complementarities among firms (Seth & Kim, 2000; Chi & Seth, 2004). Our paper is the first to use the real options framework to generate insights into intra-firm contractual arrangements vis-à-vis investments in human capital, also a context that involves complementarities between contracting parties and subject to the underinvestment problem.

A key insight of our framework is that an employment relationship contains valuable real options for each party to terminate the contract at any time. Whereas the company receives the option to dismiss employees (more generally, the option to withhold payment to employees: we call this the "company option"), workers receive the option to quit (more generally, the option to withhold effort: we call this "the worker option.") Ex ante, an investment in firm-specific human capital is undertaken when the joint benefits of investment (to the firm and workers) exceed the costs. In the face of uncertainty regarding the future value of the investment, the flexibility conferred by the options is valuable to each party. However, there are also significant costs in that exercise of the option by one party reduces the cash flows to the counterparty. The company writes the worker option and the worker writes the company option, so that the relative value of these options affects a priori returns on the investment by each party. We argue that the underinvestment problem is directly proportional to the value of these options.

Using Black-Scholes valuation,[1] we show that these options are likely to be valuable when firm-specific investment is large, when the productivity returns are variable, when the costs to exercising the options are low, and when the interest rates are low and time periods long. We posit that these factors cause the parties to develop contractual mechanisms to reduce underinvestment of human capital. We describe a variety of contractual mechanisms that can be used to mitigate this problem and the circumstances under which different mechanisms are appropriate.

FIRM-SPECIFIC HUMAN CAPITAL, LABOR MARKETS, AND CONTRACTS

Investment in firm-specific human capital is a critical ingredient in the creation of economic value. Firm-specific human capital is a classic value-creating resource, defined as an input that is inimitable, rare, without substitute, and valuable (Barney, 1991; Lepak & Snell, 1999). Firm-specific human capital, by definition, increases employee productivity in only a single company–employee dyad, so other firms cannot attempt to hire away this input with higher prices. In internal labor markets, the parties invest in firm-specific capital over a multi-year employment relationship, which is often difficult for competitors to duplicate in the short term.

Moreover, firm-specific human capital complements investments in firm-specific physical or intellectual capital (Topel, 1991). As both workers and companies try to escape commoditization and increase their wages and profits, both parties will look to invest in specialized knowledge and skills that other parties do not have. This issue is especially salient in industrialized and, now, post-industrial economies that cannot compete alone on low labor cost or low product cost.

The Problem of Incomplete Contracting

It is well known that firm specific investments have inherent contracting problems. Labor relationships, in particular, are characterized by numerous frictions including small numbers bargaining, nontransferability of property rights, asymmetric information, asymmetric enforcement of contract terms, and costly contractual negotiation and enforcement (Malcolmsonm, 1997; Dow, 1993). The key underlying terms of the labor contract involve an exchange of compensation for productivity: workers sell effort to the firm in return for wages and benefits. In labor markets with firm-specific human capital, the buyer has some power to set prices, because the worker cannot find another buyer who values the firm-specific human capital as much as the current employer (Becker, 1964). But the worker with firm-specific capital also can produce more value for the company than alternative workers, so the worker can demand higher wages from the firm. So, investments in firm-specific capital, whether human or not, are not normal financial transactions (Williamson, 1975). Unlike almost any other investment, firm-specific human capital becomes an ex post sunk cost that can never be sold or traded immediately at investment.

Small-numbers bargaining would not pose major problems if the parties could write complete contracts. However, labor market contracts are notoriously vague, in part because of asymmetric contract enforcement in which companies can be held liable while workers cannot be forced to work (Grossman & Hart, 1986; Becker, 1964). Even in cases where the parties write contracts, such as in collective bargaining agreements, labor contracts generally cover a short time period with contract fill-in over time and allow open-ended contingency clauses to cover terms not in the contract (Baron & Kreps, 1998).

Except for the simplest spot market exchanges of effort for wages, labor market contracts are never completely explicit (Rosen, 1985; Dow, 1993).[2] We define an implicit labor contract as one in which two parties agree to a set of general terms, typically the starting pay rate, the benefits package, basic role expectations, the hours and location of work, and some work behavior rules. The actual exchange of cash and effort occurs over time, based on some formal or informal negotiating process. In the context of the implicit contracts that govern investment in firm-specific human capital, both the investment itself and the payments for the investment remain open to negotiation. The firm-specific human capital investment is the cash value of time, effort, and direct costs related to a worker gaining the knowledge, skills, or abilities that constitute the firm-specific human capital. The expected future payments are the additional wages that a worker will receive for investing in the firm-specific human capital.

Despite the contractual difficulties associated with firm-specific human capital investment, it appears to be a major determinant of labor market outcomes. Since the late 1970s, researchers have studied firm-specific human capital in the context of implicit contracts (see Rosen, 1985 for a review of this early literature). Research shows that firm-specific human capital investments affect wages, training, and layoff decisions (Hammermesh, 1987; Topel, 1991; Parent, 1999; Neumark & Stock, 1999). An important conclusion from this research is that workers typically face large wage losses after being displaced from their employer and these losses persist over time (Fallick, 1996). Estimates of wage losses for displaced workers vary with the time period, sample, and measure of displacement, including estimates of 14% (Ruhm, 1991), 15% (Stevens, 1997), 25% (Jacobson, LaLonde, & Sullivan, 1993), and 27–36% (Ong & Mar, 1992). As other authors have noted, because specific training is only productive in the current firm, it would be unwise for workers to behave as they do with general training (like college or graduate school) to bear the full cost of training and then receive a wage equal to the value of post-training marginal productivity. To behave in this way is to risk a capital loss from employer-initiated layoffs (Hutchens, 1989, p. 51).

THE IMPLICIT CONTRACT TO INVEST IN FIRM-SPECIFIC HUMAN CAPITAL AND FOLLOW-ON OPTIONS

The frictions inherent in labor market contracts, as we argue earlier, can be summarized conceptually as two variables: options for both the company and employees to abandon the contract. The worker and company each receive the right, but not the obligation, to unilaterally cancel the contract when canceling provides higher returns than the contract itself. Uncertainty, combined with unenforceability, makes it likely that one party will exercise their options under certain scenarios, thereby reneging on the contract. However, neither side wants to bear the risk of the other side reneging. Their awareness of the option held by the other contracting party may cause both the company and worker to underinvest in an otherwise attractive asset.

Our analysis seeks to understand why specific human capital investments occur and how the parties reduce the costs associated with options to abandon the contract. Because our analysis is based on finance theory, we can assign precise values to the options created by labor contracts.[3] Our work is entirely consistent with previous work, but we can offer additional rigor and flexibility in analyzing firm specific human capital investments. The remainder of this paper discusses what these options are, how the options are valued, and how the parties can reduce the underinvestment problem that arises in the presence of these options.

Stylized Scenario

Consider the following scenario. A large chemical company has changed the way it converts petroleum into a consumer product.[4] By improving the conversion process, the company can produce the product more efficiently, using fewer raw materials and less energy. This process is patented and the company will not license the technology to competitors. The machine requires workers to operate a complex new software package unique to his process and to service multiple new parts on a regular basis. Clearly, the company cannot hire employees who have learned elsewhere how to operate the software and maintain the parts, so it must train employees internally.

The firm and its employees have an existing explicit or implicit employment contract that covers wages, hours, and conditions of employment.[5] The parties now must change the terms of this contract to incorporate decisions about how much to invest in firm specific training and who will finance this training. The optimal level of training exists where the marginal productivity returns from training equal the cost of training. In a scenario with frictionless contracting, the parties simply need to decide how much to invest in training, as either party could finance the investment and receive the returns. Therefore, determining the optimal level of training is a trivial problem.

In the actual world of imperfect labor market contracting, an important question is who pays for the training. At one extreme, workers could quit their current jobs, pay out-of-pocket for training courses, and then receive higher wages when they return to their jobs. At the other extreme, the company could pay employees their full wages and benefits while they enroll in formal training courses to learn the new skills. The employees then would transfer to the new machine and earn the same wage as before, presumably indifferent between the old and new job, but aware that they now have unique skills. Clearly, there is an infinite range of financing possibilities between these two extremes, although, for ease of exposition, we first examine the nature of the contracting problem under these two extreme financing arrangements.

The company prefers that workers pay for the firm-specific human capital investment, because it wants to have the option of withholding payments for past firm-specific human capital investments should those investments become less valuable in the future. This option would imply that if the new machine becomes obsolete in a few years or if consumer demand for the output falls, the company could dismiss workers who would then bear the full cost of dismissal. Depending on how wages are adjusted and when there is a decline in returns, employees would lose the financial returns gained from the prior-period firm-specific human capital investment. Workers cannot contest the dismissal because the contract is implicit, and there are no formal, written contract terms. We call this the company's option to withhold payment.

Employees prefer that the company pay for the firm-specific human capital investment, so they will have the option to withhold effort to negotiate for higher wages if the past firm-specific human capital investments become more valuable. If the new machine adds greater value than expected ex-ante (perhaps because consumer demand is stronger than expected or the new technology produces more output than expected), then the employees can demand higher wages from the company. The workers have nothing to lose by withholding effort – the company alone has financed the past investment and owns the current returns. In that case, the company must choose whether to hire and train new employees or to give the existing workers a wage increase. This is the workers' option to withhold effort.

THE OPTIONS TO WITHHOLD PAYMENT AND WITHHOLD EFFORT

The options to withhold payment and to withhold effort arise when the investment in firm-specific human capital is governed by an implicit contract. It is important to note that workers and companies almost always have these options in an employment relationship, unless there is perfect certainty and information and contracts are completely enforceable. The options arise when there are implicit contracts that govern ex post division of quasi-rents. The two parties initially agree to a division of the gains from a firm-specific human capital investment, but the actual productivity gains may be higher or lower than expected. If contracts were enforceable, the company as the residual claimant would receive both the unexpected gains and losses from the investment, as the company does with investments in physical assets or intellectual property. However, there is nothing in an implicit contract to prevent the company from voiding the contract when the gains are less than the additional wages paid to employees or to stop workers from voiding the contract to demand a larger share of the gains.

We can value these choices in the same way as financial options. The common element between these options and financial options is the presence of uncertainty: 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). The joint values of the workers' option to abandon effort and the company's option to withhold payment will be highest when actual productivity gains from a firm-specific human capital investment deviate or are expected to deviate from the expected gains.

How Are These Options Exercised?

The options to withhold payment or withhold effort represent a wide range of behaviors and activities. For workers, the essential components are to have a way to withhold effort and a way to negotiate with the company. Withholding effort could be through an official union strike, in which a group of workers receive some legal protection if they withhold effort as part of the collective bargaining process, or through less formal actions. Workers can threaten to quit, can reduce effort on the job, increase absences from work, or intentionally sabotage key outcomes. In each case, the company's productivity would fall, and there is little the company can do except fire or dismiss the worker. The worker's option to withhold effort exists only because every individual has a legal right to not work (Becker, 1964). The second component is some way of negotiating with the company. This can be a labor union, in which a group of workers elect representatives to bargain for them, employee advisory or participatory groups, or individual employee–manager negotiations (Freeman & Rogers, 1993). The worker, at any time and for any reason, can withhold effort to demand higher wages in an at will employment relationship. The company then has the choice to meet the demand, propose a compromise, dismiss the worker, or allow the worker to quit.

At will employment relationships also mean that companies can dismiss workers or reduce wages for almost any reason (Malcolmson, 1997).[6] The company also must have a way to withhold payments and negotiate with workers. In the absence of a formal labor contract explicitly limiting management rights, companies in the United States are free to dismiss workers without compensation. Even when a contract exists, companies have the option to close operations entirely, relocate operations to a foreign country, or preemptively replace unionized workers with permanent replacements in a lock-out (Cox, Bok, Gorman, & Finkin, 1996). Alternatively, the company could eliminate future wage increases (allowing inflation to reduce the real wages over time) or reduce nominal wages, although the latter is very rare.

It is not uncommon for workers and companies to exercise these options. While the incidence of strikes has fallen over time, there were between 21 and 45 major work stoppages, each involving more than 1,000 employees each year from 1992 to 2001 (Bureau of Labor Statistics). In 2000, more than 394,000 employees withheld effort for at least some time during a work stoppage, and work stoppages affected organizations as diverse as teachers in Hawaii, Seattle, Los Angeles, and Detroit, and workers at United Technologies, Boeing, Verizon, and Newport News Shipbuilding (Bureau of Labor Statistics). There is less data on workers exercising their options to withhold effort within firms. In a sample of establishments from 1997, the median establishment reported that 7% of its workforce voluntarily quit in the previous year (National Employer Survey (NES), 1997). Not every quit is the result of a worker opting to withhold effort, but there is evidence that separations occur.

Companies also have been active in dismissing employees: the 25 largest layoffs affected more than 550,000 individuals in 2001 (CBS, 2002). These layoffs seem especially common after acquisitions, in which dismissing un-ionized employees to cut costs is one way that acquisitions create value (Fallick & Hassett, 1996; Becker, 1995). In the establishment sample from 1997, more than 35% of companies reported a decline in workforce size over the past 2 years (NES, 1997). While strikes, worker quits, and layoffs have a number of causes, these are all equivalent to exercising the option to void the implicit contract.

When Are the Options Exercised?

The evidence that some workers and companies exercise their options to withhold effort and payments must be contrasted against the majority of employment relationships that do not result in strikes, quits, wage reductions or layoffs. Many workers and firms choose not to exercise their options. When options are exercised is conceptually straightforward, assuming perfect information. First, an individual only exercises an option that has positive value when the benefits exceed the costs. Second, an individual exercises an option when its present value is maximized. Individuals with a high discount rate, who tend to value future cash flows very low, will exercise earlier than those with lower discount rates. For other individuals, they will determine how the value of the option is likely to change in the future and exercise it when the present value is maximized. Of course, this problem is trivial for financial options, because the market price is the present value of the option. With the options to withhold payment and effort, there is no market price; so the parties must consider the present and anticipated future gains from exercise. It generally costs something to exercise the option, so the workers and company must weigh the present value of the gains against the present value of the costs.

For workers trying to withhold effort could result in dismissal from the firm, causing the worker to lose relationship-specific investments in signaling and human capital. The worker only withholds effort when it costs the company something if the worker leaves. The company's cost includes the cost of finding and hiring a replacement, training costs, loss of productivity during hiring and training, and similar effects, which could be a one-time cost as high as one-third of annual wages (Campbell, 1993). Workers, then, need to weigh the possible wage increases against the risk of dismissal. In many cases, the present value of the gains is unlikely to exceed the present value of the costs. Unless the worker is certain of receiving the gains, or the gains are very large, it is not value maximizing to exercise the option. In a spot-market labor contract, such as that for low-skilled workers, the threat to withhold effort has no cost to the company – it could dismiss the worker and immediately hire a comparable replacement.

The company also incurs costs upon exercising its option. Eliminating future wage increases or reducing current wage levels may prompt employees to exit the company. Dismissing workers may reduce morale and productivity among surviving employees (Wanberg, Bunce, & Gavin, 1999), and the loss in reputation may make contracting more difficult with other parties (Carmichael, 1984). In many cases, the benefits from firing workers may not exceed the costs of hiring and training new employees, motivating and compensating the remaining employees, and losing reputational capital in the broader market.

THE CONTINGENCIES UNDERLYING UNDERINVESTMENT

When options are exercised, it shifts wealth from one party to another. The same is true when options are created; if one party receives a valuable option, it is at the expense of the other party. The crux of the problem with firm-specific human capital investment is that the company receives a valuable option at the expense of the workers and vice versa. This reduces the value of the firm-specific human capital investment for the party writing the option. If workers have granted the company an option to withhold payment, the workers have created a scenario in which they lose their returns to the investment when the option is valuable to the firm, which makes their investment less likely. The same is true for the company. The presence of a valuable option, ceterus paribus, results in underinvestment in firm-specific human capital, as the affected party reduces its investment until the returns are proportionate to the investment. In some cases, this could result in no investment.

In the absence of contracting costs, these firm-specific investments would benefit all parties. Companies would have higher output and lower costs, workers would have higher wages, and the government would benefit from increased tax revenue. However, workers will not invest in firm-specific human capital when the value of the firm's option to withhold payment is high and the firm will not invest in specific human capital when the value of the workers' option to withhold effort is high. Although specific human capital investment would yield positive economic returns, those returns could be lost because of the contracting issues. Even more critical, our options model in the next section highlights that the underinvestment problem will be most severe in emerging industries that fuel future wage and output growth. As we will see, these contracting problems also affect the youngest employees who have the most years to benefit from the human capital investments.

We propose that the underinvestment problem will be most severe, and mechanisms to resolve the problem will most likely be adopted, when the joint value of the options is very high, i.e., when either the company or the workers (or both) hold a valuable option. Fig. 1 outlines the first set of necessary conditions. Note that the underinvestment problem is of significance only in the upper right quadrant, representing high uncertainty and high potential value from firm specific human capital investments. In other quadrants, either because of the absence of uncertainty or because there is little anticipated gain from such investments, the resolution of the underinvestment problem is not a significant economic problem. The next sections detail exactly when the options are valuable and how the parties contract to reduce underinvestment.

Uncertainty	LOW (Value of firm-specific human capital)	HIGH (Value of firm-specific human capital)
HIGH	**UNDERINVESTMENT/ LITTLE VALUE POTENTIAL** 1. Workers and company cannot agree to a simple contract 2. Neither party has much incentive to solve contracting problem, as value creation from the investment is limited 3. Examples: commodity competitors in turbulent industries	**UNDERINVESTMENT/ HIGH VALUE POTENTIAL** 1. Workers and company cannot agree on a simple contract. 2. Both parties create value if they can make investments 3. Will see mechanisms to reduce options values 4. Examples: differentiated companies in turbulent industries
LOW	**LOW UNDERINVESTMENT/ LITTLE VALUE POTENTIAL** 1. Workers and company can agree to a simple contract 2. Neither party has much incentive to solve contracting problem, as value creation from the investment is limited 3. Examples: commodity competitors in stable industries	**LOW UNDERINVESTMENT/ HIGH VALUE POTENTIAL** 1. Workers and company can agree on a simple contract. 2. Both parties create value if they can make investments 3. Will not see mechanisms to reduce options values 4. Examples: differentiated companies in stable industries

Value of firm-specific human capital

Fig. 1. The Underinvestment Problem.

Option Value and Theoretical Propositions

Financial and real options have two values.[7] First, there are the cash flows that accrue from exercising the option at the current time. In a labor contract, this is the amount that one party can appropriate from the other, net of the costs of exercising the option, and theoretically it can be positive, negative, or zero (clearly, the option would not be exercised if the option is out-of-the money). Second, there is the price at which someone would purchase the option at time t – its market value – that must be nonnegative. Similar to financial options, real options can be valued using the Black-Scholes model. The five primary factors in valuing an option in the Black-Scholes model are the current asset price, the underlying variability of returns, the exercise price, the interest rate and the time period (Brealey & Myers, 2000). Prices, in the context of labor market contracts, are represented by productivity and wages. For companies, the largest option value exists when an investment in relationship-specific assets is producing minimal productivity returns, but the workers are paid as though the investment was successfully raising productivity. The wage premium paid to these workers would be much greater than their productivity premium over the next best workers. For workers, the largest option value exists when that investment has resulted in extremely large productivity gains, while the workers are paid the same wages as they could receive elsewhere. In both cases, the parties have an incentive to exercise their option and break the contract, reducing the cash flows of the counterparty. The bargaining relationship, after an investment, is zero sum.

The above reasoning suggests that the firm's ability to void the contract can be considered as equivalent to the option to abandon the project represented by the investment in firm-specific human capital, which has the characteristics of a put option (see Damodaran, 2001 for a discussion of similar put options). The workers' option is somewhat more complex, and has some characteristics of a call option as well as of a put option. Note that strategy research typically has used the real options framework to investigate growth or expansion projects that have the characteristics of call options, rather than abandonment or put options as we do in this paper. One notable exception is the prior work that examines the real options associated with joint ventures, in which each party has the follow-on call (put) option to buy (sell) its stake to the other.

The parties can anticipate when options may be valuable, before they make an investment in relationship-specific assets. We will discuss five variables that affect the value of these options: the magnitude of the initial investment, the variability of returns, the cost to exercise, the interest rate and the time period. We show that the options will be most valuable in settings with large investments in relationship-specific capital, high variability in consumer demand and production technologies, weak reputation markets, low-friction labor markets, long time periods, and low interest rates. When the options are valuable, neither party initially agrees to invest in firm-specific capital. The party granting the valuable option would have lower returns, causing them to avoid investing. When the investment is economically efficient (when the present value of the productivity gains exceeds the investment cost), there is an opportunity for the two parties to improve their outcomes if they can negotiate a satisfactory contract. We propose that, when the options are valuable, the parties develop explicit contractual solutions that either compensate the counterparty for the value of the option or prevent the option from being exercised. Our propositions below highlight the specific circumstances under which these solutions are adopted. We later explain what form these solutions take. Our framework is summarized in Fig. 2.

Magnitude of the Investment

If we define the option to withhold effort or payment as an option on an arbitrary dollar value of specific investments, X, then an otherwise equivalent option on a $2X$ investment would be worth twice as much. An option on $12X$ of firm-specific human capital would be worth twelve times as much. This is similar to the value of financial options: an option to purchase $200,000 in stock will be worth ten times more than the option to purchase $20,000 in stock, ceteris paribus. An option on a more valuable asset is worth more than an option on a less valuable asset, holding all other variables constant. This implies that the parties will develop mechanisms to prevent underinvestment when the returns to and investments in firm-specific human capital are large in magnitude. Accordingly, we propose

Proposition 1. There is a positive relationship between the value of firm-specific human capital and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

The magnitude of firm-specific human capital investments is likely to vary by employee level, industry, and country. Executives make larger firm-specific human capital investments in knowledge of a company's systems, businesses, and people than front-line production or customer service employees (Singh & Harianto, 1989). In industries with high levels of corporate differentiation and unique resources, workers need to invest in more specific

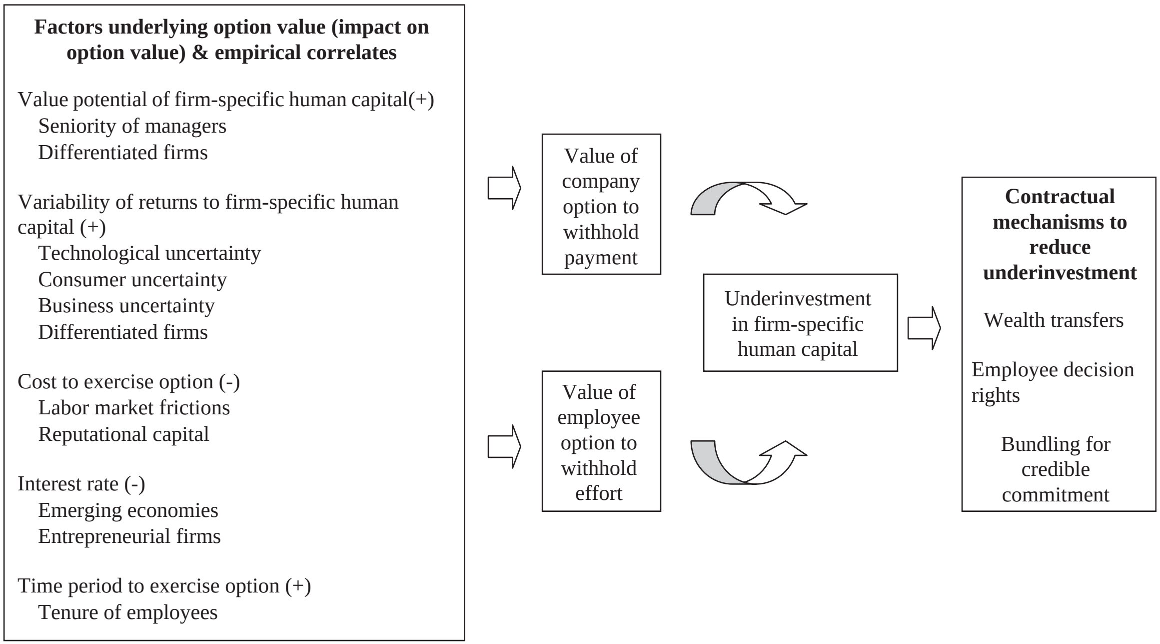

Fig. 2. The Model: Real Options and Employee Contracts.

human capital than in industries with standard resources and high levels of technological similarity (Barney & Arikan, 2001). In each case, for executives and for differentiated companies, the parties have a greater incentive to develop explicit solutions to underinvestment. We note that within a single company-worker contract, the magnitude of the investment can vary for the two parties. Both are affected by an increase in the total size of the investment, but the parties may finance different shares of that investment. When one party finances a larger share of the firm-specific investment, it increases the value of the counterparty's option, not its own option.

Variability of the Returns

In the Black-Scholes model, an option on a more variable asset is worth more than an option on a less variable asset, where variability represents the range of possible gains to exercise. If there is no variability in the returns to firm-specific human capital, then both parties know ex ante how valuable the investment will be and can design an explicit contract at low cost (Merton, 1998). When returns have a wide range of possible values, perhaps due to changes in consumer demand, the emergence of new technologies, and organizational learning, the option for both parties will have a higher value.

The variability is the dispersion of the future difference between the marginal productivity of a worker with the firm-specific human capital and the marginal productivity of a worker without the investment. If the variability has a symmetric distribution, the two parties face identical variability in returns, but there is no reason to expect that the distribution is symmetric. The company will hold a more valuable option if there is greater downside risk in technological changes or consumer demand. The opposite is true for workers: their option is worth the most when there is greater upside potential from the investment.

For the company, the worst case scenario is when ex post, changes to production technology equalize the productivity of workers who invested in firm-specific human capital with the next best workers who did not. If the original investment were governed by an explicit contract, the company would bear the full decline in the value of the investment. With an implicit contract, the company can dismiss the workers with the firm-specific human capital, thereby transferring the cost to them. There would be no productivity advantage to employing the workers with firm-specific human capital and, in fact, there would be a serious disadvantage because the company is paying higher wages as part of the implicit contract. Because the source of value in firm-specific human capital investments is future productivity gains, the returns to investment are sensitive to innovations in production technology that reduce the value of prior-period investments.

This effect is magnified if consumer demand drops, causing each additional unit of productivity to be worth less. Consumer demand also varies across time. The willingness and ability of consumers to purchase something produced with firm-specific human capital as an input can increase if they value the product more or decline if they value the product less. An increase in demand for the product, with all else equal, will normally result in higher market prices. Consumer demand variability is the dispersion of the future product prices for the output produced with firm-specific human capital.

We think that variability is likely to be a major problem in certain industries and companies. In turbulent industries with high levels of uncertainty, there will be high levels of variability in returns. These include industries with technological uncertainty (computer software, computer hardware, pharmaceuticals), consumer uncertainty (apparel retail, toys, entertainment), or business uncertainty (health care, insurance, defense, and aerospace). In each case, the nature of the industry creates uncertainty for any investment, including firm-specific human capital. Not all uncertainty is at the industry level. Companies with differentiation strategies, especially those investing heavily in firm-specific assets, likely face more uncertainty than companies with simple price-cost competition strategies. For example, we expect that Dell Computer has less variability in productivity returns than Apple Computer and that Wal-Mart has less than Target. Overall, the options have no value in any environment with stable and predictable returns to firm specific human capital, and the options value increase monotonically with an increase in variability.

> **Proposition 2.** There is a positive relationship between variability in productivity gains from firm-specific human capital and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

Cost to Exercise

An increase in the cost to exercise the option is equivalent to a decrease in exercise or strike price, and therefore reduces the value of the option. For workers, the exercise price is the cost incurred by withholding effort and risking job loss. For companies, this is the cost of abandoning payments and risking reputation losses and employee turnover. The costs to exercising the option can differ significantly for the two parties. Workers incur a large cost in exercising their option to withhold effort, as the company could fire or demote them, causing them to incur the high costs of finding and beginning a new job (including the losses they occur by losing their past productive investments in firm-specific human capital). Workers also may lose pension plan benefits and built-up vacation days and other benefits upon dismissal. Pension plans appear to increase tenure in a company, suggesting that workers in these plans have an incentive to remain with the firm (Ippolito, 1991; Dorsey, 1995). In Canada, a law requiring severance payments and advanced notice of layoffs resulted in higher employment for protected than unprotected workers, although nonunion workers paid for these protections with lower wages (Friesen, 1996). A large source of costs for workers is labor market frictions. In a frictionless labor market, workers could easily move from one job to another without incurring high job search and relocation costs. With labor market frictions, there are costs to being dismissed from a current employer: direct costs for lost income, job search, and moving to a new area and information costs. If the new employer cannot judge employee quality, then the worker may have to accept lower wages until his or her quality is revealed (Chang & Wang, 1996).

As labor market frictions increase, it becomes more costly for workers to reduce or withhold effort. Workers have particularly high costs when they have a valuable bundle of firm-specific human capital investments. A worker can threaten to withhold effort to raise returns for any single investment in firm-specific human capital, but they risk losing their returns to all the other investments they have made. If the worker commits to quit the firm and the company allows this, then the worker will be forced to abandon all her past investments in firm specific human capital, resulting in significantly lower wages in the future position.

The factors that underlie the cost of exercise for the company include payments made to employees upon involuntary separation as well as any adverse reputation consequences. If a company exercises its option and withholds payments to worker, it may have a loss in reputation capital, making it difficult for the company to make future implicit contracts (Lazear, 1979; Carmichael, 1984; Kreps, 1990). So, the value of the option to abandon is negatively associated with the magnitude of guaranteed separation payments and with the adverse reputation consequences of abandoning payment. Reputation costs affect the company by making future implicit contracts more difficult (Carmichael, 1984; Kreps, 1990). Future counterparties will not trust the company to pay future obligations, so they will insist on explicit contracts or more favorable terms in implicit contracts or the two parties will fail to reach agreements, causing higher contracting costs.

When reputation markets are efficient, the company faces significantly higher reputation costs from dismissing employees, especially without remuneration. If reputation markets have significant frictions (when reputation is noisy or cannot be observed and "priced"), the cost of exercising the option falls. In the extreme case with no reputation markets, there are no reputation costs for any option, even the most severe. Besides the efficiency of reputation markets, the cost of the reputation consequences will also depend on a number of firm-level characteristics. Emerging companies, with little past transactional history, will have little-to-no reputation capital, so they may have little to lose from exercising the options. Likewise, companies in commodity or price-based industries, such as steel or farm products, have relatively simple transactions and contracts that can be mostly explicit, so reputation capital may matter less. In large, established companies with prominent brand names, such as Coca-Cola, Procter & Gamble or Ford, the company's reputation may be so valuable that they would not exercise an option at almost any price unless they fairly compensate the workers.

Overall, the value of options cannot be realized unless the parties exercise them by withholding effort or abandoning payments. If the cost to exercise the option is higher than the gains to exercise, then the option will not be exercised. At a very high cost to exercise, the options will have no value. Conversely, reducing the cost to exercise will result in higher values for the options. Options have the most value in environments with no reputation consequences for companies and no labor market frictions for workers.

> **Proposition 3.** There is a negative relationship between the level of job market frictions and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

> **Proposition 4.** There is a negative relationship between the magnitude of reputation consequences and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

Interest Rate and Time Period

In the Black-Scholes model of options valuation, the exercise price (the cost to exercise the option) and the possible market prices (the gains from exercising the option, which is a function of variability in returns) are critical determinants of an option's value and are dependent on the terms of a specific options contract, the investment in firm-specific human capital. Two other factors are also important determinants of an option's value: the interest rate and time period. An increase in the interest rate will reduce the value of the options. The interest rate relates the future value of cash flows to present values; when the interest rate is very high, even large cash flows gains in the future have a very low value today. Likewise, as the interest rate approaches zero, the present value increases. For contracts in an economy or organization with high interest rates, such as an emerging economy or new business venture, the effect will be to decrease the value of the options.

Proposition 5. There is a negative relationship between the interest rate and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

Note that for a new business venture or an emerging economy that is characterized by high underlying variability of the value of the investment in firm-specific human capital, high interest rates would have an effect counter to the variability effect.

Options covering a longer time period are always worth more. When the contract covers a long period, it is more likely that gains to exercising will exist during at least one period. We define the time period above as the expected company tenure of employees making the investment. The time period will be longer for young workers who expect to remain at the company for their entire careers. When the time period is long, it is likely that one party will have a valuable option in at least 1 year, leading to exercise.

Proposition 6. There is a positive relationship between the expected tenure of the employee in the firm and the use of contracting mechanisms to reduce underinvestment, ceteris paribus.

CONTRACTUAL MECHANISMS TO REDUCE UNDERINVESTMENT

Our discussion below examines how various mechanisms might reduce the underinvestment problem by their impact on the value of the company and worker options. In financial markets, these mechanisms do not exist, because the two parties can adjust market prices until both buyers and sellers are willing to transact. We note first that changing prices in labor market exchanges is equivalent to adjusting wages: if the workers grant a valuable option to withhold payment to the company, then the company could simply increase wages until the worker is willing to make the investment. This has the benefits of simplicity and low costs, as the parties would not need to make any other contractual agreements. However, an increase in wages paid to workers has the effect of increasing the value of the company's option, as it becomes more attractive to break the contract when workers are paid higher wages. If the company elects to pay higher wages to employees, its option value would increase, which would prompt the employees to demand even higher wages. Wage payments are implicit mechanisms that increase options values, so adjusting wages is not a viable mechanism to reduce underinvestment.

More generally, any implicit guarantee simply creates new options or makes existing options more valuable. Only explicit mechanisms will solve the underinvestment problem. We next outline three explicit mechanisms: wealth transfers, employee decision-rights, and credible bonding. These mechanisms reduce underinvestment by transferring wealth or preventing the options from being exercised.

Wealth Transfers

One explicit guarantee is to transfer wealth upon agreeing to the contract. If the workers have the valuable option to withhold effort, they could agree to accept significantly lower wages for a short period to compensate the company for the option, which frequently occurs in apprenticeships, training programs, and internal labor markets. Similarly, if the workers grant the company a valuable option, the company would offer a signing bonus, one-time payment, or higher wages for a short period. The benefit of an initial wealth transfer is its simplicity and transparency. Interestingly, when there is a very large cash transfer, both parties expect ex ante that the contract will be broken and that the option holder will exercise the option. This must be true because the option creates value for the holder only when it is exercised, so a high-value option indicates that either the option is likely to be exercised, or the returns upon exercise would be very significant, or both. The initial wealth transfer is necessary to convince the other party to invest in firm-specific human capital, knowing that the relationship is unlikely to last for multiple periods.

Alternatively, the parties could agree to transfer wealth when the contract ends. Workers can promise a wealth transfer, such as losing pension and other retirement benefits, losing equity in the firm, losing seniority benefits, or agreeing to no-compete clauses, if they exit the firm after withholding effort. There is evidence that workers investing in firm-specific human capital are more likely to receive pension benefits and tend to receive high pension benefits (Johnson, 1996). Companies can make credible commitments to transfer wealth upon exercising their options to withhold payment, either through severance packages, early retirement plans, vesting of retirement, or equity-sharing plans, or through golden parachutes (Jensen, 1988).

We note that while transferring wealth ex ante or ex post is a simple and transparent mechanism to reduce underinvestment, it may have undesirable side effects. Investments in firm-specific human capital have a signaling value when it is otherwise difficult to measure productivity (Lazear, 1995). A person willing to invest in firm-specific human capital signals that he or she will remain with the firm for a long period to recoup the investment cost. Firms can require workers to make this investment to screen out workers who are not willing to commit to a long tenure with the company, potentially reducing its total human resource costs. If firm-specific human capital investments signal worker attributes, then transfers from companies to workers is likely to distort the value of the signal. Also, because firm-specific human capital investments increase worker wages in a single firm relative to all other firms, workers who have made these investments in the past have an incentive to provide high effort on the job to eliminate almost any chance of dismissal or other termination. Past investments in firm-specific human capital, then, can act as an incentive for workers to provide more effort than they otherwise would (Lazear, 1981; Lazear & Rosen, 1981; Rosen, 1986).

Employee Decision Rights

Labor unions have been shown to be effective at increasing worker wages by shifting rents and quasi-rents from the company to workers (Becker & Olson, 1992; Hirsch, 1991; Freeman & Medoff, 1984), and in punishing companies for breach of contract (Hogan, 2001). Unions represent a shifting of decision rights from the company to the workers, although these rights generally cover specific business operations and the terms and conditions of employment. Unions may make it more difficult for a company to withhold wages because of superior bargaining power compared to workers negotiating individually. However, as discussed early in this paper, unions and firms typically do not bargain over corporate and business strategy, which have a major effect on the decision to exercise the company's option.

One way that workers could reduce the likelihood of the company's options being exercised is to receive an explicit set of decision rights through involvement in corporate governance or an ownership stake in the company (Blair, 1995, 1996, 1999). Employee governance is the transfer of voting rights over corporate decisions from shareholders to employees. This could occur by placing one or more employee-directors on the board of directors with full voting rights and information privileges. An alternative to board representation is that workers could receive exclusive decision rights over a narrower set of issues most important to them, as in a works council in Germany (Addison, Kraft, & Wagner, 1993; Pistor, 1999; Roe, 1999). In the United States, similar decision rights are held by high performance work groups. Rather than have limited rights to participate in all the company's decisions, this option gives workers nearly complete ownership of a limited number of decisions. These decisions could include the terms and conditions of employment, changes to overall employment systems, and perhaps even corporate strategies that affect workers. Employee governance can make it extremely difficult for the employer to reduce wages or eliminate workers when returns to firm-specific human capital fall.

Note that employee governance is unique is that it reduces the value of the company's option, but it is counterproductive at reducing the value of worker's option (it would actually increase that value). Employee governance is likely very effective to mitigate underinvestment that arises from situations where the company has a high options value, but it will exacerbate underinvestment in cases when the workers' option is very valuable. In that latter case, the workers would need to transfer significant wealth (through reduced wages) at the inception of the contract or would need to invest a large amount in other relationship-specific assets to bond themselves to the firm.

Bundling and Credible Bonding

High performance human resource practices include incentive pay, flexible staffing, teams, high levels of employment security, and high training investments (Ichniowski, Shaw, & Prennushi, 1997). Research consistently shows that high-performance human resource practices have a strong positive effect on firm performance and employee productivity (Huselid, 1995; Delery & Doty, 1996; Delaney & Huselid, 1996; Ichniowski et al., 1997). These practices seem to increase employee wages in at least some industries (Bailey, Berg, & Sandy, 2001) and to reduce employee turnover (Huselid, 1995). Why this effect exists is a puzzle. Lepak and Snell suggest that firms rely on high performance human resource systems to develop unique, valuable human capital in employees, a conclusion similar to early work that connected unique human capital to the existence of internal labor markets (Lepak & Snell, 1999; Doeringer & Piore, 1971; Williamson, 1975).

Our analysis suggests a different mechanism linking high performance human resource systems and human capital acquisition. An investment in a commitment-based human resource system locks the company into a bundle of management practices, with firm-specific human capital as a critical part of that bundle. This "lock-in" represents a credible commitment by the firm not to exercise its option to abandon payments in the future. If the company chooses to exercise its option, it would need to simultaneously change its entire human resource system, as it would lose the firm-specific human capital part of that system. By linking its broader management practices to firm-specific human capital, the company is bonding itself to employees and signaling credibly that it will not exercise its option. This increases the returns to firm-specific human capital investment to employees, reducing any underinvestment problem from the company holding a valuable option. In this model, the additional investments in firm-specific human capital increase employee wages, reduce turnover, and improve corporate financial performance. Importantly, the commitment-based human resource practices themselves do not have any necessary effect on firm performance (although they may), as the company chooses them to send a credible signal to workers.

Bundling resources reduces the options value by making it harder to exercise the options. If firm-specific human capital is an integral part of a broader system (for the company, its human resource or production system and for workers, a set of relationship-specific investments), neither party may choose to exercise their options. When human capital is integrated with other investments, withholding effort or withholding payments can result in losses on those other investments, making it prohibitively costly to exercise the option. Companies can create credible commitments not to exercise by developing an entire corporate architecture than relies on firm-specific human capital, such that the gains to abandoning payments would be outweighed by the losses from switching its entire human resource management system. This helps companies to commit to not abandoning payments for firm-specific investments, if the firm does not want to sacrifice the entire management system for those gains. Workers also create credible commitments not to exercise their options by investing in bundles of firm-specific assets. The gains to withholding effort on any single investment would be balanced by the potential losses of the remaining firm-specific assets.

SUMMARY AND CONCLUSIONS

This paper complements previous research on firm-specific human capital by applying real options analysis to this investment. The parties receive valuable options to exit the contract when information becomes revealed in the future, but these options may be more valuable for one party than the other. Companies and workers then attempt to reduce the value of the options through contractual mechanisms that either shift wealth to the party granting the option or prevent the option from being exercised. In both cases, the mechanisms cause the parties to invest in firm-specific capital, resulting in higher output and higher wages.

Our analysis is consistent with but has a number of advantages over prior approaches such as transactions cost economics (TCE) (see Williamson, 1981) that have also analyzed the contracting problems with firm-specific human capital. In our model, the value of the option to withhold payment and to withhold effort may be considered analogous to the risk of holdup due to asset specificity (as highlighted by TCE). Similar to TCE, a real options analysis of the employment contract recognizes that asset specificity gives rise to a *mutual* holdup problem. However, the solutions are different. TCE proposes that the problem is solved by the authority relationship that characterizes a firm so that "bilateral gains introduce an opportunity to realize gains through hierarchy" (Williamson, 1991, p. 271). However, assuming that employees (a) are not slaves so they may indeed withhold effort or quit their jobs, and (b) cannot "buy" the company they are employed by, the underinvestment problem cannot be solved by one party "owning" the other or exercising "authority."

Second, the options model is parsimonious. All relevant variables – the value of training, the value of signaling, external labor market forces, reputation markets, and others – can be summarized by two values: the options granted to the worker and company. The labor contract, then, can be modeled as an explicit contract plus two options to abandon the contract.

Third, although parsimonious, a real options analysis identifies new theoretical insights into factors that influence the risk of holdup and thereby how employee contracts are structured. For example, our real options framework explicitly introduces the cost of exercising the option into the analysis. So, even in a situation characterized by high uncertainty and high asset specificity, the so-called "holdup problem" would be mitigated by reputational effects or frictions in labor markets. Although we have not focused on the timing of the exercise of the option in this paper, it is worth noting that in the presence of uncertainty, a company (worker) might wait to exercise its option to hold up the worker (company) since exercising the option to holdup may be more valuable in the future.

Fourth, we show that the various solutions to underinvestment (internal labor markets, high performance work systems, severance packages, pension plans, efficiency wages, golden parachutes, employee governance, unions) should be modeled as a continuum of solutions to the same problem. The real options frameworks explains how it may be efficient for one firm to encourage employee unionization and ownership of the company, while another firm simply pays its workers a signing bonus to pay for the risks associated with firm-specific human capital investments.

In a broader sense, we believe that a real options view has the considerable potential to contribute to the literature on the theory of the firm. In general, this literature analyzes the problem from a static perspective, and in general, does not explicitly incorporate a consideration of how uncertainty about how the future might unfold, and how the associated value of flexibility associated might impact the scope of the firm. Numerous papers in this volume directly or indirectly contain implications for this central issue (e.g., Maritan & Alessandri, 2007; Cuypers & Martin, 2007). We believe that incorporating the dynamic elements of real options logic into the theory of the firm offers a particularly fruitful area of research inquiry for the future.

NOTES

1. The options we consider here are akin to American options, which can be exercised at any time prior to expiry. Although the Black-Scholes model is generally used for valuing European options (that have a pre-defined date on which they can be exercised), it is appropriate to use as a guide to the value of the company and worker option since an American option entails a European option (and will be worth at least as much as the European option).

2. One of the authors accepted his first job knowing only the employer and annual salary, leaving everything else open to later negotiation. Even carefully worded Hollywood and sports contracts focus primary on compensation and contract risk, not on performance expectations of the employee.

3. While assigning precise values to the options is feasible, this paper only presents the conceptual framework, not a quantitative analysis of real options values in labor contracts.

4. The company is the residual claimant of the net revenue from the production process. Because the company receives all residual profits, it will initially receive any positive or negative economic rents arising from the implicit contract. The company is assumed to act unilaterally as a collective whole, despite its actual composition as a potentially large number of owners and managers. The company achieves optimal utility when it minimizes wage costs conditional on achieving a certain level of output and revenue.

5. Workers are defined as any group of employees investing in similar levels of human capital, under similar contract terms, and with similar variability in expected returns to the investment. This group could be as small as one individual or as large as an entire workforce. This model assumes that workers have similar utility functions, preferences, and external job opportunities, so they can act collectively as a

unified whole. The workers achieve optimal utility by maximizing wages conditional on work hours, risk, and other conditions of employment.

6. Generally, companies cannot dismiss members of protected classes, including women, racial minorities, veterans, and the disabled and older workers, for discriminatory reasons. Workers also may be protected from dismissal if they have received explicit tenure guarantees (as for teachers, federal judges, and some others) or if they are covered by a formal labor contract with seniority rules (as for labor union members).

7. Numerous excellent references (e.g., Brealey & Myers, 2000) describe financial options in depth.

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PART V:
PERFORMANCE IMPLICATIONS OF REAL OPTIONS

AN EXAMINATION OF OPTIONS EMBEDDED IN A FIRM'S PATENTS: THE VALUE OF DISPERSION IN CITATIONS

Tailan Chi and Edward Levitas

ABSTRACT

This paper applies and empirically tests a real options approach to conceptualizing the value of patents. Based on a theorem derived by Merton (1973), we propose that greater dispersion in the citations of a firm's patents represents greater flexibility for the firm to exercise the option rights embedded in the patents and thus enhances the option value of the patents. A test of this proposition using a sample of 128 US-based biotechnology firms found corroborative results.

INTRODUCTION

Since the theory of real options was first introduced to the study of strategic and technology management, many authors have proposed that a firm's R&D efforts create technology options for the firm (e.g., Kester, 1984; Mitchell & Hamilton, 1988). Although this notion appears theoretically

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sound and its basic intuition may have influenced managerial decision making long before it was clearly articulated, there has been limited work undertaken to test it empirically. The empirical study of Folta (1998) suggests that pharmaceutical companies treat partial equity investments in or joint ventures (JVs) with biotechnology startups as means for acquiring technology options. Levitas and Chi (2001) found evidence that the stock market values a firm's patenting as creation of technology options. Specifically, their results indicate that a firm's success in patenting has a more positive impact on its Tobin's q when there is higher uncertainty in the technological field of the firm. The literature on financial and real options has shown a robust theoretical relationship between the value of an option and the extent of uncertainty about the value of the asset underlying the option (Merton, 1973; Dixit & Pindyck, 1994). This well-known theoretical relationship, however, was not carefully documented until recently in empirical studies with regard to the value of options that are considered to be based on a firm's R&D outcomes.

The objective of the present paper is to explore further the determinants of the value of technology options that may be embedded in a firm's patents. The economic value of a firm can be conceptually divided into two components: the *value of discounted cash flows* from the firm's existing operations and the *value of options* embedded in the firm's tangible and intangible assets (Myers, 1977). It is, however, difficult to measure the option value of a firm separately from its cash flow value. One approach that has recently been developed to calculate the value of a firm's growth options is to subtract from the firm's market value the value of its assets in place (Tong & Reuer, 2006), but the implementation of this method relied on proprietary data on the investment activities of the firm. Although one can potentially construct somewhat simplified versions of this measure using publicly accessible data (e.g., Compustat and CRSP), the accuracy of such simplified measures remains to be tested. Without being able to measure a firm's option value directly, any test of propositions on the value of options held by a firm requires the empirical researcher to find variables that in theory affect its option value but not its cash flow value. For instance, any direct measure of the quality of a firm's patent portfolio can reflect not only the effect of the patents on the firm's options but also their effect of its cash flow value from current operations. One variable that has been used effectively in testing propositions relating to effect of options is the extent of uncertainty about the value of the underlying assets (e.g., Folta, 1998; Levitas & Chi, 2001). Other variables that existing option models have shown to affect option value include the risk-free rate of interest and the chance of competitive preemption (Dixit & Pindyck, 1994; Trigeorgis, 1996). But these variables can also be easily related to the cash flow value of the firm either by themselves or through other variables with which they are likely correlated. For instance, the interest rate affects the firm's cost of borrowing and thus also influences the value of its cash flows; it can also be highly correlated with time, which is in theory a factor affecting the value of the firm's cash flows. Measures that reflect the vulnerability of a technology to competitive preemption, such as the competitive dynamics of the industry and the effectiveness of patent protection in the industry, can also be expected to influence the cash flows of the firm from its ongoing operations.

The focus of this paper is to test a proposition based on a theorem that Merton (1973) derived with regard to the value of financial options. The proposition involves a variable that in the context of technology patents is not expected to influence the value of the firm's cash flow value on the basis of existing theories. Using a mathematical model, Merton (1973, p. 148) showed that a portfolio of options on multiple assets is more valuable than an option on a portfolio of assets. Some of the implications that this theorem has for strategic management are explored in Bowman and Hurry (1993). We adapt the basic idea of this theorem to the context of technology options to develop a proposition about the impact of the dispersion in the citations of a firm's patents on the value of the options embedded in the firm's patents. Our regression analysis of data from a sample of 128 US-based biotechnology firms yields results consistent with our proposition, providing support for the notion that a firm's patents afford the firm strategic options in technology.

The rest of the paper is organized as follows. The next section applies Merton's theorem to analyze the value of options embedded in a firm's patents and derives our main proposition. The paper then explains the data and econometric methods used in our empirical analysis, and presents the results of the analysis. The last section discusses the results and concludes the paper.

THE VALUE OF DISPERSION IN PATENT CITATIONS

A considerable amount of research has examined the effect of a firm's patents on its market value, with somewhat ambiguous results (Levitas & Chi, 2001). For example, Blundell, Griffith, and Van Reenen (1999), Deng, Lev, and Narin (1999), Griliches (1981), Megna and Klock (1993), and

Pakes (1985) find that the number of patents granted to a firm positively impacts Tobin's q or similar measures of firm market value. Cockburn and Griliches (1988), however, find that the effect of patent holdings disappears when the regression equation also includes a measure of the firm's past R&D investments. Works by Austin (1993), Ben-Zion (1984), Connolly, Hirsch, and Hirschey (1986), and Shane and Klock (1997) suggest that investors may even be indifferent about whether firms have received new patents for their technological inventions. Decarolis and Deeds (1999) find that a firm's patent holdings have a negative impact on its stock market performance. More recently, Hall, Jaffe, and Trajtenberg (2005) find that patents weighted by the citations they receive by subsequent patents positively impacts investors' perceptions of firm value. Levitas and Chi (2001), suggesting that patents have option-like characteristics and thus that their values should increase with the level of uncertainty, find that exogenous or "unmanageable" uncertainty moderates this relationship between citation-weighted patents and investor perceptions. However, no research to our knowledge examines how the *dispersion* of these citations across patents affects a firm's market valuations. We undertake such an examination in this paper.

Merton (1973, p. 14) derived a theorem that can be stated as follows. Let S_i for $i = 1, 2, \ldots, n$ denote the unit price of an asset, which is one of n assets under consideration. Assume that the prices of all the n assets are the same, i.e., $S_i = S_j = S$ for $i, j = 1, 2, \ldots, n$. Define $z_i(t)$ to be a random variable representing the one-period return per dollar invested in the ith asset, and let $Z_i(\tau) = \sum_{t=1}^{\tau} z_i(t)$ denote the τ-period return per dollar invested in the asset. Then, consider an artificially constructed portfolio that consists of exactly the same n assets and has a τ-period return per dollar $Z_{n+1}(\tau) \equiv \sum_{i=1}^{n} \lambda_i Z_i(\tau)$, where $0 \leq \lambda_i \leq 1$ is the fraction of the money invested in the ith asset, subject to the restriction $\sum_{i=1}^{n} \lambda_i = 1$. Merton showed that an option on the portfolio is not as valuable as a portfolio of options on the n individual assets. The theorem can be stated more precisely as $F_{n+1}(S, \tau; E) \leq \sum_{i=1}^{n} \lambda_i F_i(S, \tau; E)$, where $F_i(S, \tau; E)$ denotes the value of the option on the ith security for $i = 1, 2, \ldots, n+1$ and E denotes the exercise price[1].

The basic idea of this theorem is that holding a portfolio of options on multiple assets affords greater flexibility and thus provides a higher value than holding an option on a portfolio of the same assets. The flexibility stems from the fact that the holder of the option portfolio is able to exercise the option on each asset individually depending on whether they are in the money while the holder of the option on the asset portfolio can only purchase all the assets in the portfolio including those that are out of the money. The assumptions under which the theorem is derived (e.g., the returns on all the assets in the portfolio being identically distributed) are clearly difficult to apply strictly to options based on patented technologies. But the theorem's basic approach to assessing the value of flexibility can be used to develop a proposition on the value of technology options.

It is reasonable to assume that each patent represents a distinct piece of technology based on the prevailing scientific and legal criteria. Even though the knowledge covered in a single patent may not be sufficient to create a new product or production process, it must contain a sufficiently integrative and potentially useful set of knowledge for the inventor to file it for a patent and for the patent office to grant the patent.[2] Even if commercial application of a patent may require a combination of the knowledge covered by the patent with the knowledge covered by other patents, the patent holder still has the flexibility to exercise its rights to each patent individually. So, we can consider the option to use or license the technology covered by each patent to be a stand-alone option, with the asset underlying the option being the discounted cash flows from potential applications of the technology in the future. Based on this line of reasoning, the portfolio of patents held by a firm constitutes a portfolio of options.

For the ease of exposition, consider two firms that both possess some patented technologies whose potential applications are still highly uncertain but expected to yield the same cash flow value for the two firms. Suppose for the moment that Firm A's technologies are so integrative that each piece has little value without the others and thus cannot be used separately from the rest while Firm B's technologies are not so interdependent and are thus patented separately. Then, Firm B has greater flexibility in exercising the options embedded in its patented technologies than does Firm A. In reality, however, the cash flow potentials of different patents vary both within the same firm and across different firms. Although it is difficult to measure precisely the potential cash flow value of the technology covered by a given patent, research has suggested that the number of citations a patent receives in subsequent patents provides a measure for the patent's potential value (Trajtenberg, 1990). If the potential value of a patent is measured by the number of the citations it receives, the number of patents is an error-prone measure for a firm's flexibility in exercising the options embedded in its patent portfolio. We suggest that a dispersion measure of the citations that a firm's patents receive (while controlling for other factors) can provide an indication of the flexibility the firm has in exercising its technology options.

Now consider two firms that each have two patents and six citations of their patents in total: the six citations of Firm A's patents are spread evenly between the two (three each) while the six citations of Firm B's patents all fall on one of its two patents. If we measure the value of a patent by the number of citations it receives, then Firm A has two equally valuable patents while Firm B has one patent with substantial value and one patent with little or no value. Based on the number of citations, the value of Firm A's patents is the same as that of Firm B's patents. But because one of Firm B's patents is deemed to have little or no value by the citation measure, the firm has only one meaningful technology option residing in that valued patent. In this sense, Firm A has greater flexibility than Firm B in exercising their technology options embedded in the patents that they each possess. Such flexibility is critical given that the development of potentially valuable technology does not guarantee any appropriation (or realization) of that value. Indeed, in most cases, patented technologies are *never* transformed into marketable products (Albert, Avery, Narin, & McAllister, 1991). In some cases, the technology simply does not work in practice as it did in testing (witness, e.g., the efficacy of pharmaceutical candidates in animal models that is not replicated in human subjects). In other cases, competing products preempt the profitable commercial introduction of a technology. A deficiency in complementary assets, such as trained sales force, manufacturing capacities, or even a legal team needed to defend the legitimacy of the patented technology, may also reduce the commercial viability of a technology (e.g., Teece, 1986). Thus, greater flexibility in terms of decisions with which to confront contingencies is critical to vitality in technological dynamic environments.

We, therefore, propose the following:

Proposition 1. The dispersion in the citations of a firm's patents, Ceteris paribus, adds value to the options embedded in its portfolio of patents.

Tobin's q is a measure of a firm's value that reflects its future investment opportunities. It is derived by taking the ratio of the firm's market value to the replacement cost of its assets in place, yielding a measure that is proportional to the value created from its existing assets. Lang, Stulz, and Walking (1989) suggest that this measure reflects the marginal return on investment in the firm or the investment opportunities facing the firm. Theoretically, it varies with both the value of discounted cash flows from the firm's existing operations and the value of options that the firm holds. As pointed out in the introduction, the quality of a patent (e.g., as measured by the citations it receives) is also expected to influence both its cash flow value and its option value. Even though existing theories do not predict unambiguously how the effect of a firm's patents on its cash flow value varies with the dispersion in their citations, the above proposition suggests that citation dispersion positively moderates the effect of its patents on the firm's option value. Based on the presumption that Tobin's q is correlated with the firm's option value, we hypothesize:

Hypothesis 1. There is positive interaction between the number of citations a firm's patents receive and the dispersion in the citations among the patents, Ceteris paribus, in influencing Tobin's q.

Prior research has suggested that the stock market places a higher value on a firm's patent citations when there is greater technological uncertainty because the option embedded in the firm's patents is more valuable at the time of higher uncertainty (Levitas & Chi, 2001). Simply stated, patents provide the firm with technology options that are valuable when there is a chance for the current technology to become obsolete because of new technological developments in the industry. The value of such options is greater when there is higher uncertainty in the firm's technology environment because the discretionary nature of the investment need to exploit the patented technologies allows the firm to benefit from the greater upside potential associated with the higher uncertainty without facing a higher downside risk (Dixit & Pindyck, 1994).

Hypothesis 2. There is positive interaction between the number of citations a firm's patents receive and the level of uncertainty in the industry, Ceteris paribus, in influencing Tobin's q.

Based on the same reasoning, we suggest that the option value attributable to the dispersion in the citations of a firm's patents is also enhanced by the level of uncertainty. The additional flexibility gained from a more dispersed distribution of the citations is likely to yield greater value at the time of higher uncertainty again because uncertainty raises both the upside potential and the downside risk, the latter of which is truncated by the discretionary nature of the investment needed to exploit the options.

Hypothesis 3. There is positive interaction between the dispersion in the citations among a firm's patents and the level of uncertainty in the industry, Ceteris paribus, in influencing Tobin's q.

METHODOLOGY

Sample

Our sample is drawn from a population of US-based biotechnology firms engaged in pharmaceutical research from the years 1989–1999. We chose this industry because patents are viewed as providing effective protection for a firm's technological inventions in the industry (e.g., Sorensen & Stuart, 2000). By collecting our data from a single industry, we can avoid potential industry confounds as well as difficulties in interpreting meanings of patents across varying technological and appropriability regimes (e.g., Ahuja, 2000; Sorensen & Stuart, 2000).

To select our sample, we used journal articles, US Securities and Exchange Commission filings, and industry publications to identify all publicly traded US biotechnology companies that were engaged in the (non-generic) development of human therapeutics between 1989 and 1998. This procedure resulted in the identification of 298 companies. We discarded 26 firms whose panels were composed of a single observation (due to our use of a lagged dependent variable as described below, firms were required to have at least two consecutive years of observations to be included in our sample). Due to missing financial data, we also omitted 144 firms as well as a number of observations from firms included in our sample (in almost all cases, firms included in this latter category were listed on a US public stock exchange but had abbreviated or no effective "public" lives). In sum, our screening procedures as well as data availability, and firm failure or acquisition, limited our sample to 128 firms consisting of 470 firm-year observations.All patent information was obtained from the US Patent and Trademark Office's (PTO) *Automated Patent System* online database, the PTO's *Cassis* database, CHI Research, Inc., and the National Bureau of Economic Research *Patent Data Files*. All other data were taken from the Compustat and the Center for Research in Security Prices (CRSP) US stock database.

Variables

Dependent Variable

Tobin's q ($q_{i,t}$). We measure Tobin's q as the sum of the firm's market value of equity, book value of preferred stock, and book value of total debt, divided by the book value of its total assets. Chung and Pruitt (1994) showed that this measure is highly correlated with other widely used measures of Tobin's q. We use $q_{i,t}$ to denote the value of Tobin's q for firm i in year t. The notations for the other variables described below follow the same convention.

Independent Variables

Citation Intensity ($CI_{i,t}$). We measure this variable as the number of citations received by the patents that a firm produced in a given year, standardized by the firm's total assets in that year. Similar to academic journal articles, a patent that receives a larger number of citations by subsequent patents is more valuable in the scientific sense. Therefore, citations are likely to reflect the scientific as well as economic value of a firm's patents (Trajtenberg, 1990; Sampat & Ziedonis, 2004). We perform a citation count for each patent by totaling citations in the five years following the date of patent issue (e.g., Levitas & Chi, 2001). This measure is similar to that employed previously (e.g., Hall et al., 2005; Megna & Klock, 1993).

Citation Entropy ($CE_{i,t}$). To measure the degree of dispersion of a firm's patent citations, we use a version of the entropy construct discussed by Jacquemin and Berry (1979) and others, but standardize this construct by the natural log of a firm's total yearly patents. Citation entropy is calculated in the following manner:

$$\text{Citation Entropy}_{i,t} = \frac{\sum_{k=1}^{N_{i,t}} (c_{k,i,t}/C_{i,t}) \ln(C_{i,t}/c_{k,i,t})}{\ln(N_{i,t})}$$

where $N_{i,t}$ is the number of patents that firm i produced in year t, $c_{k,i,t}$ for $k = 1, 2, \ldots, N_{i,t}$ is the number of citations that each of the $N_{i,t}$ patents received in the first 5 years after their issue, and $C_{i,t}$ is the total number of citations that the $N_{i,t}$ patents received in the same time period. This measure gauges how evenly the citations of a firm's patents are dispersed among its patents. The behavior of the measure is illustrated by the examples presented in Table 1. As one can see, the score increases as the citations become less concentrated on a small number of patents (i.e., moving up each column of the table or moving rightward in each row in the three lower panels of the table). Firms with the same number of citations and with the citations equally distributed across their patents receive identical scores, regardless of the number of patents over which citations are distributed.

This "standardized" measure of Citation Entropy is very conservative in the sense that it essentially removes the effect of the number of patents on the dependent variable (see, e.g., Soofi (1992) for a more detailed description

Table 1. Behavior of the Measure of Citation Entropy.

Patent No.	Citations per Patent	Patent Count	Share of Citations	Raw Entropy	Citation Entropy	Patent No.	Citations per Patent	Patent Count	Share of Citations	Raw Entropy	Citation Entropy
1	2	1	0.2500	0.3466		1	2	1	0.2000	0.3219	
2	2	1	0.2500	0.3466		2	2	1	0.2000	0.3219	
3	2	1	0.2500	0.3466		3	2	1	0.2000	0.3219	
4	2	1	0.2500	0.3466		4	2	1	0.2000	0.3219	
						5	2	1	0.2000	0.3219	
Total	8	4	1.0000	1.3863	1.0000	Total	10	5	1.0000	1.6094	1.0000
1	3	1	0.3750	0.3678		1	3	1	0.3000	0.3612	
2	2	1	0.2500	0.3466		2	2	1	0.2000	0.3219	
3	2	1	0.2500	0.3466		3	2	1	0.2000	0.3219	
4	1	1	0.1250	0.2599		4	2	1	0.2000	0.3219	
						5	1	1	0.1000	0.2303	
Total	8	4	1.0000	1.3209	0.9528	Total	10	5	1.0000	1.5571	0.9675
1	4	1	0.5000	0.3466		1	4	1	0.4000	0.3665	
2	2	1	0.2500	0.3466		2	2	1	0.2000	0.3219	
3	1	1	0.1250	0.2599		3	2	1	0.2000	0.3219	
4	1	1	0.1250	0.2599		4	1	1	0.1000	0.2303	
						5	1	1	0.1000	0.2303	
Total	8	4	1.0000	1.2130	0.8750	Total	10	5	1.0000	1.4708	0.9139
1	5	1	0.6250	0.2938		1	5	1	0.5000	0.3466	
2	1	1	0.1250	0.2599		2	2	1	0.2000	0.3219	
3	1	1	0.1250	0.2599		3	1	1	0.1000	0.2303	
4	1	1	0.1250	0.2599		4	1	1	0.1000	0.2303	
						5	1	1	0.1000	0.2303	
Total	8	4	1.0000	1.0735	0.7744	Total	10	5	1.0000	1.3592	0.8445

of the behavior of the entropy measure). It is in fact more conservative than our theoretical proposition demands. We see two advantages in using such a conservative measure. First, by using a measure that is not correlated with the number of citations, we can avoid the potential problem of double counting and any ensuing confounding effect. The number of patents is highly correlated with the number of citations in our sample. Second, a more conservative measure also allows us to have greater confidence in any significant results that we may find.

Technological Uncertainty (σ_t). Following Folta (1998), we measure the level of technological uncertainty characterizing the biotechnology industry as the volatility in stock price index of ten representative firms in the field. Such uncertainty is viewed as exogenous as it results from factors that are beyond the control of any individual firm. To control for trend effects in stock prices, volatility measures were constructed from a generalized autoregressive conditional heteroscedasticity (GARCH) estimation (e.g., Folta & O'Brien, 2004; Greene, 1997). This method accounts for the returns' serial correlation over time (thus, removing any variance due to a time trend) and assumes a heteroscedastic error structure (i.e., that variances may not be uniform over time).

Control Variables
Class Intensity ($CL_{i,t}$). The USPTO assigns each patent to one or more ''classes'' in order to group patents that contain ''similar subject matter'' (U S Patent and Trademark Office, 1997, p. 3). Class categorizes patents into technological areas of invention. To control for the possibility that dispersion of patents across varying technology areas affects firm value, our estimations include a Class Intensity variable, measured as the total yearly number of unique USPTO assigned classed to a firm's patents, divided by a firm's total patents in that year.

Natural Log of Total Patents ($TP_{i,t}$). We natural log transformed a firm's yearly patent productivity to control for the possibility that patenting proficiency affects stock market valuation. We used the natural log of total patents to reduce potential heterskedasticity problems.

R&D Stock Intensity ($RD_{i,t}$). Following Henderson and Cockburn (1994), we create an R&D ''stock'' measure to estimate a firm's aggregate investment in research and development activities. We add to the current year's R&D expenses each of the previous four years' R&D expenses. The lagged values of R&D are depreciated by 15% per year. This measure reflects the fact that R&D expenses in a single year do not fully capture the anticipated benefits of R&D activity in a given year. We calculate this measure by dividing each firm's annual R&D stock by the firm's total assets. Some authors suggest that R&D spending may reflect a different aspect of a firm's intangible capital than patenting (Megna & Klock, 1993). So, it is important to control for the effects of this variable in our study.

Year Dummies (Y_t^s). We inserted the year dummies for years 1989–1998 to control for any omitted year effects. We use Y_t^s to denote the dummy variable for year s in year t; its value is 1 for $s = t$ and 0 otherwise.

Lagged Dependent Variable ($q_{i,t-1}$). We include a lagged dependent variable to control for other omitted variables (Greene, 1997).

Model and Estimation

Based on the preceding discussion, our empirical model can be specified as follows:

$$q_{i,t} = \mathrm{CI}_{i,t} + \mathrm{CE}_{i,t} + \sigma_t + (\mathrm{CI}_{i,t} \times \mathrm{CE}_{i,t}) + (\mathrm{CI}_{i,t} \times \sigma_t) + (\mathrm{CE}_{i,t} \times \sigma_t) + \mathrm{RD}_{i,t} + \mathrm{CL}_{i,t} + \mathrm{TP}_{i,t} + Y_t^s + q_{i,t-1} + \varepsilon_{i,t}$$

where $\varepsilon_{i,t}$ is an error term. This specification introduces a problem of potential inconsistency in estimation because the lagged dependent variable is likely to be correlated with the error term (Greene, 1997). Arellano and Bond (1991) developed an estimator using the generalized method of moments (GMM) that allows for the estimation of dynamic panel data models of the sort described above. We used their two-stage estimator and calculated the robust estimator of the covariance matrix of the parameter estimates as specified by Windmeijer (2005) in our study. We centered all variables involved in interaction terms to reduce the incidence of multicollinearity problems.

RESULTS

The correlation matrix and summary statistics for the variables used in our study are provided in Table 2. The results of our panel data analyses are

Table 2. Means, Standard Deviations, and Correlations[a,b].

	Mean	Std.	1	2	3	4	5	6	7	8	9	10
1. Tobin's q	4.43	3.98										
2. Lagged Tobin's q	4.14	3.14	0.65***									
3. Citation entropy	0.19	0.40	−0.03	−0.09+								
4. Technological uncertainty	0.009	0.92	0.18***	−0.12	0.05							
5. Citation intensity	−0.10	0.06	0.25**	0.03	−0.14***	0.05						
6. R&D stock intensity	1.58	4.37	0.06	−0.006	−0.006	−0.05	0.26***					
7. Class intensity	0.40	0.17	−0.02	0.13*	−0.18***	−0.07+	0.23***	0.009				
8. Total patents in natural logs	2.10	0.99	−0.08+	−0.17***	0.35***	0.11*	−0.39***	−0.06	−0.62***			
9. Citation intensity × citations entropy	−0.02	−0.04	0.07	0.10+	−0.84***	−0.07	0.15***	0.08+	0.21***	−0.38***		
10. Citation intensity × technological uncertainty	0.002	0.12	0.01	0.10+	−0.07	−0.66***	0.25***	−0.01	0.11*	−0.12**	0.07+	
11. Citation entropy × technological uncertainty	0.02	0.45	0.08+	−0.01	−0.22***	0.25***	−0.03	−0.01	−0.02	0.02	0.26***	−0.31***

[a] $N = 470$.
[b] Correlations estimated using centered values of variables involved in interactions.
+ $p < .100$.
* $p < .050$.
** $p < .010$.
*** $p < .001$.

reported in Table 3. Model 1 involves only the main effects of the explanatory and control variables; Models 2–4 have the interaction terms entered individually; Model 5 includes all the interaction effects that we hypothesized in this study. Autocorrelation does not seem to bias our models as indicated by insignificant Arellano-Bond tests for first- and second-order autocorrelation. Models presented in Table 3, as noted above, are estimated with robust standard errors.

The χ^2 tests indicate that all the models are statistically significant overall. The last two rows of Table 3 report the results of Hansen's J tests and C tests, respectively. Because the Arellano-Bond estimator uses the GMM to compute the values of the coefficients in two stages, the estimates would be subject to biases if any of the instruments used in the first stage are correlated with the error term. Hansen's J statistic provides a test of the null hypothesis that all the instruments are orthogonal to the error term (Hansen, 1982). None of the J tests are significant, indicating that all instruments used in the first-stage estimations are orthogonal to the error term. The C statistic we estimate provides a test of the null hypothesis that a subset of the instruments used is a significant contributor to the explanation of the endogenous variables. The tests fail to reject the null hypothesis in each of the relevant models, showing that each of the interaction terms makes a significant contribution. In this sense, the C test serves the same purpose for the GMM two-stage estimator as the F test for the ordinary least squares (OLS) estimator in testing the significance of a subset of variables.

We suggested in Hypothesis 1 that the Citation Intensity–Citation Entropy interaction would positively predict Tobin's q. Support for this hypothesis is found in Model 2 where the coefficient of the Citation Intensity–Citation Entropy interaction was positive and significant (4.24; $p<.05$). Further support for this hypothesis is found in Model 5 where the coefficient of this interaction was also positive and significant (2.17; $p<.05$). The plot in Fig. 1 graphically illustrates how citation entropy enhances the effect of citation intensity on Tobin's q.

Support for Hypothesis 2 (in which we predicted that the Citation Intensity–Technological Uncertainty interaction would positively predict Tobin's q) was found in Model 3. In this model, the Citation Intensity–Technological Uncertainty interaction was positive and significant (9.62; $p<.001$). Further support was found in Model 5 where the coefficient of this interaction was also positive and significant (8.68; $p<.001$). A plot of this interaction is provided in Fig. 2. Consistent with Levitas and Chi (2001), this figure indicates that citation intensity has a stronger effect on Tobin's q when there is higher

Table 3. Arellano Bond Estimation of the Effects on Tobin's q of Entropy and Technology Uncertainty[a,b].

	Model 1	Model 2	Model 3	Model 4	Model 5
Lagged Tobin's q	0.26^{+}	0.30*	0.31*	0.26^{+}	0.33*
	(0.14)	(0.14)	(0.14)	(0.14)	(0.15)
Citation entropy	0.36*	0.18	0.25	0.52^{+}	0.43**
	(0.15)	(0.26)	(0.20)	(0.28)	(0.15)
Technological uncertainty	9.71***	9.67***	10.38***	9.62***	10.24***
	(2.38)	(2.41)	(2.62)	(2.48)	(2.28)
Citation intensity	8.40^{+}	10.03^{+}	19.25***	8.12	17.04***
	(4.76)	(5.66)	(4.37)	(5.10)	(4.27)
R&D stock intensity	0.04	−0.01	−0.01	0.05	−0.00
	(0.07)	(0.05)	(0.04)	(0.07)	(0.05)
Class intensity	−1.18	−1.58	−1.81^{+}	−0.99	−1.63^{+}
	(1.15)	(1.14)	(1.10)	(0.96)	(0.99)
Total patents in natural logs	−0.23	−0.14	−0.19	−0.31	−0.22
	(0.40)	(0.35)	(0.39)	(0.34)	(0.33)
Citation intensity × citation entropy		4.24*			2.17*
		(1.83)			(0.89)
Citation intensity × technological uncertainty			9.62***		8.68***
			(2.64)		(2.19)
Citation entropy × technological uncertainty				0.30^{+}	0.49***
				(0.16)	(0.14)
χ^2	102.43***	100.25***	91.05***	77.77***	280.61***
Hansen's J	108.59	116.09	108.37	107.16	117.15
C statistic		7.50	−0.22	−1.43	8.56

[a]$N = 470$.
[b]Robust Standard Errors in parentheses; coefficients of year fixed effects omitted from table.[c]C statistics computed vis-à-vis Model 1.
$^{+}p < .100$.
$^{*}p < .050$.
$^{**}p < .010$.
$^{***}p < .001$.

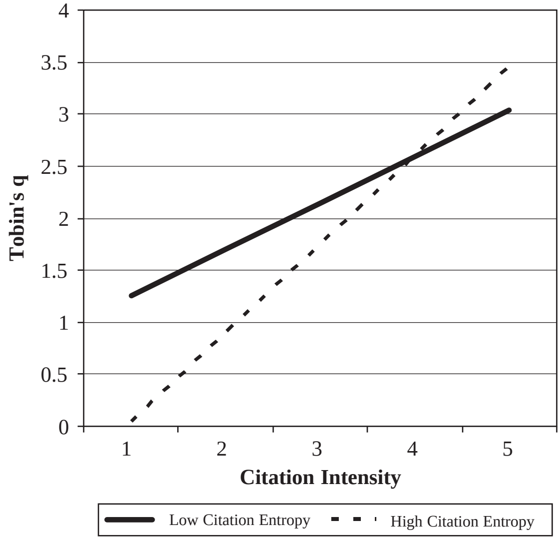

Fig. 1. Effects of Citation Intensity on Tobin's *q* at Differing Levels of Citation Entropy.

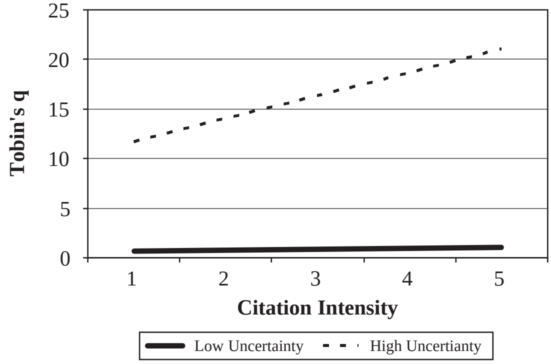

Fig. 2. Effects of Citation Intensity on Tobin's *q* at Differing Levels of Technological Uncertainty.

technological uncertainty. Furthermore, the relationship between citation intensity and Tobin's *q* is relatively "flat" at a low level of uncertainty, suggesting that citation intensity does not produce a commensurate increase in Tobin's *q* when there is little uncertainty.

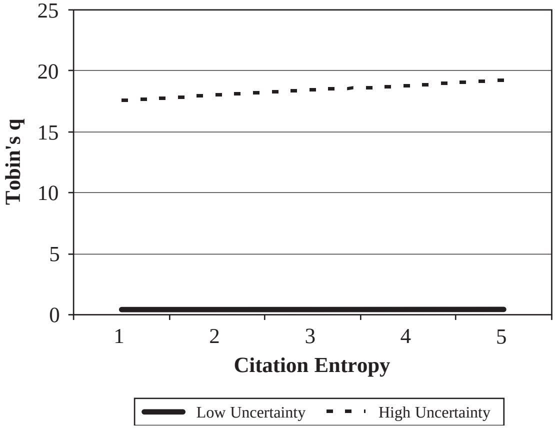

Fig. 3. Effects of Citation Entropy on Tobin's *q* at Differing Levels of Technological Uncertainty.

Per Hypothesis 3, we predicted that the Citation Entropy–Technological Uncertainty interaction would positively predict Tobin's *q*. In Model 4, the coefficient of this interaction was positive (.30) and moderately statistically significant ($p < .10$). Support for this hypothesis was also found via Model 5, where the interaction coefficient was found to be both positive and significant (.49; $p < .001$). A plot of this interaction is provided in Fig. 3. Similar to that depicted in Fig. 2, this suggests that citation entropy is more valuable in conditions of high technological uncertainty. This is to be expected if patents have option-like characteristics.

CONCLUSION

A challenge to testing propositions derived from applications of real options theory to research questions in strategy management is that the value of a real option in general can not be directly measured. The same applies to the option value of patents that is the focus of this study. Consequently, empirical researchers need to find alternatives to measuring the value of real options directly. One approach is to treat the unobservable value of real options as a latent variable and examine how the explanatory variables influence observable decisions that in theory depend on the value of the unobservable real option value (e.g., Folta, 1998; Nerkar, Paruchuri, & Khaire, 2007). Another approach is to examine how the explanatory variables influence some measure of firm value that in theory varies with the option value of the firm (e.g., Levitas & Chi, 2001). A difficulty with this second approach is that the common measures of firm value (e.g., stock price or Tobin's q) reflect both the cash flow value of the firm and the value of options the firm holds. Unless the explanatory variable in question is a priori deemed to have no effect on the cash flow value of the firm, there is always ambiguity about whether any effect the variable is found to have on the measure of firm value reflects its effect on cash flow value or option value. In the context of this study, the variable that in theory directly explains the option value of a firm's patents is the quality of the patents measured as their citation count. It is, therefore, often necessary to find a variable that moderates the theoretical relationship between the option value of the firm and the explanatory variable in question but does not affect the relationship between the cash flow value of the firm and the same explanatory variable. The use of such a moderator in the analysis enables the researcher to tease out the effect of the explanatory variable on the firm's option value from its effect on the firm's cash flow value. The main contribution of this study is the identification of a new variable – the dispersion of patent citations – that in theory can enhance the option value of a firm's patents but has no a priori predictable effect on their cash flow value.

Because patented technologies from a firm's R&D efforts offer it the flexibility with regard to future technology choices, it seems intuitive that this flexibility represents real options that add value to the firm. Although the theoretical linkage between R&D efforts and real options has been recognized for more than two decades (e.g., Kester, 1984; Mitchell & Hamilton, 1988), there has been limited work to test this linkage empirically due to the measurement difficulties as noted above. This paper presents results that verify the option value of patented technologies despite the difficulty in measuring directly the value of options embedded in a firm's patents. Based on a theorem that Merton (1973) derived from a mathematical model, we proposed that the dispersion in the citations of the patents that a firm has produced from its R&D efforts enhances the value of the technology options embedded in those patents. The number of citations that a patent receives has been widely used as an indication of its potential value in the scientific as well as commercial sense. The numbers of citations vary both among the patents of the same firm and between the patents of different firms, presumably due to their differing scientific and commercial potentials. The basic reason for the proposition is that the dispersion of this citation value among a firm's patents increases its flexibility in exercising the options embedded in its patents. The flexibility comes from somewhat different but related conditions. First, assuming that each patent covers a relatively self-contained set of knowledge, a patent holder is likely to face more difficulty in slicing up the knowledge embodied in a single patent than the knowledge covered by different patents when it tries to exercise the options embedded in its patents. Second, it is likely to provide a more effective technology hedge for a firm to have the citation value of its patents dispersed among different patents than having the citation value concentrated on a smaller subset of the patents.

The results from our empirical analysis are consistent with our theoretical proposition. Specifically, our results suggest that the citations of a firm's newly obtained patents have a more favorable effect on the firm's Tobin's q when the citations are more dispersed among the patents. In congruence with a previous study (Levitas & Chi, 2001), our results also show that the effect of the firm's patents on its Tobin's q is enhanced when there is greater uncertainty in the industry. Along the same line, we also obtained some (albeit weak) evidence that the dispersion of the citations among a firm's patents is valued more favorably when there is greater uncertainty in the industry.

Our study provides further evidence that technology patents afford firms with valuable options and that the stock market places value on the possession of patents particularly at the time of high uncertainty. It also reinforces evidence that patent value, due to the option-like nature of patents, is highly contingent on external conditions (Levitas & Chi, 2001). Patents confer their owners various strategic and technologically based choices whose likelihood of pursuit will vary depending on changing economic circumstances. Existing models of financial and real options show a number of conditions that influence the value of an option, including volatility in the value of the underlying asset and flexibility in the exercise of the option. In our study, we used the technological uncertainty measure to proxy volatility in the value of options embedded in a firm's patents and the citation entropy measure to reflect flexibility of exercise. Our finding that both measures moderate the effect of patent citations on Tobin's q has implications for the evaluation of a firm's patent portfolio, which is an integral component of any acquisition, merger, and alliance formation process.

The hypotheses tested in this study are derived from existing option models that are not specifically constructed to examine options embedded in a firm's patents. Certain assumptions of the general models are restrictive and difficult to satisfy in the context of patent options (e.g., the assumption of Merton's (1973) model that the returns on all the assets in the portfolio are identically distributed). Although the basic principles on which the results of the general models are based are applicable to the specific type of options that we examine, any divergence of modeling assumptions could lower the precision in the derivation of our hypotheses. The only way to enhance the precision of theoretical reasoning and empirical specification is perhaps to develop models exactly tailored to the structures of patent options. Another important benefit from developing such specialized option models is the potential for uncovering additional explanatory variables or theoretical relationships that can be employed in future empirical studies of options residing in technology patents. So, more precise theoretical modeling is in our view an important research direction that future studies of strategic options in general and patent options in particular should pursue. A notable step that has been taken in this direction is the model that Oriani (2007) developed to study technology switching options.

As we noted in the introduction and in the beginning of this section, a major challenge to empirical research in strategic management under the real options framework is the difficulty in measuring the value of a real option. In this study, we used Tobin's q to gauge the change in the value of real options held by the firm; but this measure is in theory also influenced by the cash flow value of the firm, presenting noise in the analysis. There is, therefore, potential for future studies to improve the precision in measurement by constructing new measures that are less influenced by the cash flow value of the firm. One notable step that has been taken in this regard is the development of the growth option measure by Tong and Reuer (2006) based on proprietary data. An interesting challenge to future researchers is to construct alternative versions of this measure using publicly accessible data and determine their accuracy. So, another important step that in our view future studies should undertake is the development of alternative measures and databases that will allow empirical researchers to measure more precisely the option value of the firm. It is worth noting that researchers in financial economics have developed measures for the values of other types of options that are likely also of interest to researchers in strategic management, such as the measure for the value of abandonment options constructed by Berger, Ofek, and Swary (1996).

Real options theory is a general approach to the study of decision making under uncertainty and can potentially yield greater insights if integrated with other approaches to strategic decision making. In this volume, Cuypers and Martin (2007) develop a theoretical paper that integrates real options theory with a number of other theoretical perspectives such as transaction cost economics and cognitive psychology to study joint ventures and the evolution of their structures under uncertainty. We believe that such integration can also benefit the study of other strategic choices such as technology investment and innovation. It is important, however, for any integration of the real options approach with other theoretical approaches to examine carefully their commensurability in assumptions and logic to ensure theoretical coherence and precision.

NOTES

1. The exercise price is, in general, specified in a financial option contract. In the case of technology options embedded in patents, the exercise price can be thought of as the initial cost of investment for commercializing the technology concerned, although the investment cost in general can only be estimated.

2. Patents (in most cases) are granted if the underlying technology meets the *novelty*, *usefulness*, and *nonobviousness* criteria. To meet the novelty standard, patents must describe new products or processes, which are not "anticipated" by the current state of practice in a given field of invention (Barrett, 1996, p. 20). To be useful, patented inventions must have the potential to provide some economic benefit to the society in which they are granted. Accordingly, "merely demonstrating that the invention fills space is insufficient" for patent granting (Barrett, 1996, p. 37). Finally, patentable inventions cannot be "obvious to a person having ordinary skill in the pertinent art as it existed when the invention was made" (Barrett, 1996, p. 32). In other words, assignees cannot patent commonly understood/used products or processes.

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TECHNOLOGY SWITCHING OPTION AND THE MARKET VALUE OF THE FIRM: A MODEL AND AN EMPIRICAL TEST

Raffaele Oriani

ABSTRACT

The valuation of innovation investments still poses several unresolved questions. Although some authors have analyzed these problems within a framework based on real options theory*, their work has not explicitly tested the value of specific real options. The model of firm market value presented in this paper formally includes a* technology switching option*, which allows a firm to exchange an existing technology with a new technology. We test the model on a panel of publicly traded British firms operating in different manufacturing industries. The results provide support to the claim that the stock market recognizes and evaluates a technology switching option.*

INTRODUCTION

Different actors within the economic system need nowadays more accurate methods to assess the value of a firm's innovation-related intangible assets

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(Lev, 2001). However, evaluating innovation still poses several unresolved questions. A stream of empirical studies has addressed these problems analyzing the relationship between different measures of innovation and the market value of the firm (see Hall, 2000 for a review). Although this issue has been extensively investigated, the empirical and theoretical debate on the factors affecting the market valuation of innovation-related assets is still open (Hall, 2000; Oriani & Sobrero, 2003).

In response to these questions, some authors have tried to re-analyze the relationship between innovation and market value within a different framework based on *real options theory* (Bloom & Van Reenen, 2002; Oriani & Sobrero, 2002; de Andrés Alonso, Azofra-Palenzuela, & de la Fuente-Herrero, 2005; Reuer & Tong, 2007a). However, in none of these papers there is an explicit modeling of the real options created by a firm's innovation investments. On the other side, several authors have modeled innovation within a real options perspective with increasing sophistication (e.g. Grenadier & Weiss, 1997; Weeds, 2002). While providing interesting insights on the timing of R&D investment and the innovation adoption process, these works have not produced empirically testable models.

Indeed, we are still lacking an empirical validation of the predictive power of evaluation models based on real options theory. This shortcoming is mainly due to the difficulty of defining reliable option valuation parameters being able to reflect the complexity of the 'real' investment domain (Lander & Pinches, 1998; Luehrman, 1998; Copeland & Tufano, 2004). Very few works have calculated and tested the value of real options in specific fields, such as petroleum leases (Paddock, Siegel, & Smith, 1988) or real estate contracts (Quigg, 1993), where the option parameters are more easily available being contractually determined. A notable exception is the paper of Berger, Ofek, and Swary (1996), which has tested whether stock market investors evaluate an abandonment option, i.e., the option to abandon a firm at its exit value. The authors have calculated the value of this option and then assessed its relationship with firm market value. Following this approach, the main objective of this paper is to calculate the value of a real option and analyze its effect on firm value. In particular, in our model the market value of the firm embeds a *technology switching option*, which is the opportunity to exchange a real asset (present value of the future cash flows from an existing technology) with a potentially more valuable one (present value of the future cash flows from a new technology). When technology is a primary source of uncertainty, the opportunity to switch to a new technology becomes critical for firm value and even survival (McGrath, 1997; MacMillan & McGrath, 2002; Oriani & Sobrero, 2002; Anand, Oriani, & Vassolo, 2007).

In order to evaluate this option, we moved from the models already available in the financial literature (e.g. Margrabe, 1978) and more recently applied to the valuation of innovation projects (e.g. Pennings & Lint, 1997; Schwartz & Moon, 2000). The model presented in this paper also recognizes that the potential exercise of the technology switching option depends on the probability that a firm adopts the new technology and that this probability differs across firms. In this way, it tries to account for the stochastic nature of innovation at the firm level, following previous theoretical contributions on R&D competition (see Reinganum, 1989 for a review).

We test our model on a panel of publicly traded British firms operating in different manufacturing industries. We gathered data from analyst estimates and patent databases in order to define the parameters needed for the valuation of the technology switching option. The results show that the financial market positively evaluates the technology switching option held by a firm. Moreover, they suggest that a higher probability to innovate increases the value of the technology switching option at the firm level. The regression fit significantly improves when the technology switching option is included in the analysis, indicating that the model built and tested in this paper better explains the relationship between innovation and firm market value.

This paper offers several contributions to previous literature and practitioners. First, it builds a model of the firm's market value explicitly including a real option, which is accurately defined and evaluated. Second, it provides support for the claim that the market valuation reflects the value of an option created by the firm through its innovation activity. Third, it validates a valuation tool for innovation investments that can find useful applications.

The rest of the paper is organized as follows. In the next section, theoretical and empirical work on technology and real options, with a focus on switching options, is reviewed. In section "The model", the model is defined, whereas in section "Data and variables" the variables and the option parameters are described in detail. In section "Results" the results of the empirical analysis are presented and in the final section the main conclusions, implications and limitations of the paper are discussed.

TECHNOLOGY SWITCHING OPTION AND FIRM VALUE

The effect of innovation on firm value is hardly predictable, mainly because of the high degree of uncertainty related to the technical success and the evolution of market demand and technology within the industry. The valuation methods based on discounted cash flows, assuming investors' risk-aversion and the non-changeability of the firms' actions once planned, normally fail to fully capture the value of innovation (Kogut & Kulatilaka, 1994). Indeed, an emerging group of scholars have proposed a new theoretical framework to analyze the value of innovation based on the *real options theory*, which builds on the analogy between financial options and investment opportunities in 'real' assets (Trigeorgis, 1996). The idea that investments in innovation create opportunities that are analogous to the options traded in the financial markets has been widely accepted by the literature on the management of innovation (e.g. McGrath, 1997; Huchzermeier & Loch, 2001). Several models have been elaborated for the valuation of R&D projects (e.g. Pennings & Lint, 1997; Perlitz, Peske, & Schrank, 1999; Schwartz & Moon, 2000, among others) and patents (Pitkethly, 2006). In this respect, 'to a much greater extent than rival techniques, real options can help companies make their way through the maze of technological and market uncertainties that face them when they make their decisions' (Copeland & Keenan, 1998, p. 141).

However, although recent theoretical contributions in real options have reached a significant level of sophistication in modeling several features of innovation investments (e.g. Grenadier & Weiss, 1997; Weeds, 2002), we are still lacking a strong empirical validation confirming the predictive power of real options models to assess the value of innovation-related assets and, in the end, the value of the firm. A pioneering empirical study on patent and real options has been realized by Pakes (1986). The author used data on patent renewals in conjunction with an option-based model of patent holders' decisions to estimate patent returns. More recently, Ziedonis (2002) analyzed firms' decisions to acquire commercialization rights for University technologies within a real options framework. Yet, these studies have not related real options to the overall firm value.

Other authors referring to the vast body of literature on innovation and market value (e.g. Hall, 2000) have tested the presence of a real options logic in the market valuation of innovation. Oriani and Sobrero (2002) have adopted a real options logic to analyze whether market and technological uncertainty affected the stock market valuation of firms' R&D investments. Consistent with the predictions of the real options framework, they showed that market and technological uncertainty do affect the market valuation of R&D investments. Bloom and Van Reenen (2002) reported that in the face of greater uncertainty, firms decide to hold an option to wait not embedding the knowledge created through R&D activities in new products or processes.

This leads to a loss of productivity in periods of greater uncertainty, as shown by the estimation of a productivity function. Another stream of literature has tried to asses the value of a firm's growth options. Following the work of Kester (1984), they have measured the value of growth options as the difference between firm market value and the value of the assets in place, which is assumed equal to the capitalized value of the current earnings (e.g. Danbolt, Hirst, & Jones, 2002; Tong & Reuer, 2006; Alessandri, Lander, & Bettis, 2007). The value of the growth options has also been related to several firm-specific variables, such as R&D investments and joint ventures (de Andrés Alonso et al., 2005; Reuer & Tong, 2007a).[1] Indeed, even adopting a real options logic, none of these studies tested an analytic model of the option value.

We could then gain new insights from a model of the firm's market value explicitly including and evaluating a real option generated by innovation investments. Some recent contributions in the management field have advanced that firm's R&D investments generate new technological assets that can be placed 'on the shelves' waiting for new information on market and technology evolution (Garud & Nayyar, 1994). Miller (2002, p. 690) has claimed that 'the willingness of firms to invest in idle technologies reflects their interest in maintaining flexibility to switch technologies in the future'. Kulatilaka and Trigeorgis (1994) have modeled the flexibility to switch, recognizing that the value of an innovation project is the sum of the value of the rigid project and the value of the option to switch technologies in the future.

Thus, investments in innovation create options allowing a firm to switch to an emerging technology in the future (McGrath, 1997). A fairly high number of studies have demonstrated how the emergence of a new technology in an industry can critically affect the performance and even the survival of firms selling products based on the existing technology (see Hill & Rothaermel, 2003 for a review). Relevant examples include subsequent generations of disk drives (Christensen, 1997), quartz vs. mechanical wristwatches (Glasmeier, 1991), traditional vs. biotech drugs (Kaplan, Murray, & Henderson, 2003), optical vs. digital cameras (Tripsas & Gavetti, 2000) and UMTS vs. GSM in mobile phones (Liikanen, Stoneman, & Toivanen, 2004). When a new technology emerges as a dominant standard in the industry, a firm not adopting it could be able neither to competitively sell products based on the existing technology nor to re-enter later in the market embodying the new technology into their products (Schilling, 1998). In this perspective, an option to switch has a high value because it reduces the negative consequences of investing in the wrong technology (McGrath, 1997; MacMillan & McGrath, 2002; Oriani & Sobrero, 2002; Vassolo, Anand, & Folta, 2004). Consistent with this interpretation, Hatfield, Tegarden, and Echols (2001) showed that technology hedging is more likely in the period of technological ferment preceding the emergence of a dominant design, but they did not provide an empirical validation of a closed form of switching option.

Building on these arguments, we advance that firms investing in innovation hold an option to switch to a new alternative technology in the future if this proves to have a higher value in the new competitive environment. A switching option is therefore the opportunity to exchange a real asset (present value of the future cash flows from an existing technology) with a potentially more valuable one (present value of the future cash flows from a new technology). Given the expected demand for a firm's products, this difference depends on the degree of substitution between the two technologies. A series of events related to the technology or the institutional context can favor the adoption of the new technology (Arthur, 1989). A technology switching option takes its maximum value, which is equal to the value of the new technology, when the value of the established technology falls to zero due to its complete substitution. This situation is analogous to the switching option originally defined for the financial assets (see Margrabe, 1978), which is the option to exchange one financial asset with another. Accordingly, we will formulate and test a model of firm market value in which a *technology switching option* is formalized and evaluated.

THE MODEL

Market Value of the Firm

Previous models of the market value of the firm (e.g. Griliches, 1981; Hall, 1993a, 1993b) have not addressed two significant aspects of the relationship between innovation and market value: the stochastic nature of innovation and the discretional, option-like nature of the firm's decision to adopt it. Building on the emerging issues of real options theory, the aim of the model formulated in this paper is to include the value of the potential benefits from future stochastic innovations into the firm's market value equation. To this purpose, we assume that the value of the firm has two different components. The one is deterministic and consists of the present value of the expected cash flows from the assets in place conditional on all the available information, whereas the other is represented by the potential benefits from future unpredictable innovation and can be modeled as an option. This approach is consistent with the seminal work of Myers (1977) and more recent empirical contributions (Berger et al., 1996; Berk, Green, & Naik, 1998; Jagle, 1999; Tong & Reuer, 2006).

Traditional literature in financial economics has argued that the value of a firm at time 0 should be equal in perfectly competitive markets to the present value of its expected cash flows conditional on the set of available information at time 0 (Fama & Jensen, 1985). Assuming that the present value of expected cash flows of firm i at time 0, $s_{i,0}$, is a function of its tangible assets ($A_{i,0}$) and technological knowledge capital ($K_{i,0}$) at time 0, we can express the market value of the firm i at time 0 ($V_{i,0}$) as follows:[2]

$$V_{i,0} = f[\varphi(A_{i,0}, K_{i,0})] \tag{1}$$

where $\varphi(A_{i,0}, K_{i,0})$ is the capital aggregator function. If we choose a linear functional form for the capital aggregator, as in Hall (1993b), expression (1) becomes

$$V_{i,0} = b(A_{i,0} + \kappa K_{i,0}) \tag{2}$$

where b is the market valuation coefficient of a firm's total assets reflecting its differential risk and monopoly position, κ the relative shadow value of the technological knowledge capital to tangible assets, and the product $b\kappa$ the absolute shadow value of the technological knowledge capital. In practice, $b\kappa$ reflects the investors' expectations on the overall effect of $K_{i,0}$ on the present value of the expected cash flows, while κ expresses the differential valuation of the technological knowledge capital relative to tangible assets (Hall, 1993b). Expression (2) can be interpreted as the basic version of the model that is known in literature as 'hedonic pricing model', where the good being priced is the firm and the characteristics of the good are its assets, both tangible and intangible (Griliches, 1981).[3]

However, as discussed in the previous section, a new technology can emerge in industry j at an uncertain time t^*. A firm i that has invested in the new technology holds an option to switch between the existing and the new technology. This option has to be exercised no later than time τ_j, since the technology progress in industry j deprives the adoption of the new technology of any economic value after that time. If a new technology emerges before or at time τ_j, it can be either adopted or not by firm i at time τ_j.[4] Its eventual adoption shifts the present value of expected cash flows of firm i from $s_{i,\tau}$ to $\hat{s}_{i,\tau}$, where s_i and $\hat{s}_i$ are stochastic variables. Firm i will decide to adopt the new technology at time τ_j *if and only if* the condition $\hat{s}_{i,\tau_j} > s_{i,\tau_j}$ holds. We define $W_{i,0}(s_i, \hat{s}_i, \tau_j)$ as the value at time 0 of an option to switch between s_i and $\hat{s}_i$ at time τ_j. If we account for the value of this option, expression (2) can be rewritten as follows:

$$V_{i,0} = b[A_{i,0} + \kappa K_{i,0} + \delta W_{i,0}(s_i, \hat{s}_i, \tau_j)] \quad (3)$$

where δ is market valuation coefficient of the technology switching option. Whereas in Eq. (2) the coefficient κ was supposed to assess the overall expected effect of the technological knowledge capital on firm value, in Eq. (3) it should be related only to its effect on expected cash flows since the potential benefits from future unpredictable innovations are now measured by the coefficient δ. We then expect the coefficient κ to be lower in Eq. (3) than in Eq. (2). In practice, the introduction of $W_{i,0}$ should allow us to discern the effect of technological knowledge on expected cash flows of the existing technology, measured by κ, from the effect of technology switching option on firm value, measured by δ.

Eq. (3) can be transformed, as done by several previous studies (e.g. Cockburn & Griliches, 1988; Hall, 1993b; Blundell, Griffith, & Van Reenen, 1999), dividing both members by $A_{i,0}$ and then taking the natural logs:

$$\ln\left(\frac{V_{i,0}}{A_{i,0}}\right) = \ln b + \ln\left[1 + \frac{\kappa K_{i,0}}{A_{i,0}} + \frac{\delta W_{i,0}(s_i, \hat{s}_i, \tau_j)}{A_{i,0}}\right] \quad (4)$$

Based on the model presented in Eq. (4), if the stock market recognizes and evaluates accordingly a technology switching option, we expect the following:

H1. The technology switching option positively affects firm market value ($\delta > 0$)

Technology Switching Option

In order to evaluate the technology switching option $W_{i,0}(s_i, \hat{s}_i, \tau_j)$ we need a closed valuation formula. We moved from the model originally proposed by Margrabe (1978). This is a generalization of the Black and Scholes (1973) formula that evaluates a European option to exchange one asset with another. This model presents the limit to evaluate a European option, which implies that, different from an American option, the option cannot be exercised before its maturity. Some more recent models have combined the switching option with the compound option to evaluate a European sequential exchange option (Carr, 1988) and even an American sequential exchange option (Carr, 1995; Lee & Paxson, 2001). These formulations would represent the technology switching option more realistically when innovation programs are organized in stages and provide the firm with sequential investment opportunities that can be exercised at the end of each stage. However, we decided to rely on Margrabe (1978) formula because this is more parsimonious in terms of the number of parameters required for the estimation. This is a relevant aspect, since one of the main limitations for the practical applications of real options theory is the difficulty of calculating reliable input parameters for the valuation formulas (Lander & Pinches, 1998; Luehrman, 1998). This problem can become particularly severe when the option values are simultaneously computed for firms operating in different industries, as we do in this paper. Assuming that both s_i and $\hat{s}_i$ follow a geometric Brownian motion, Margrabe (1978) evaluates a switching option as follows:

$$
\begin{aligned}
W_{i,0} &= \hat{s}_{i,0}N(d_1) - s_{i,0}N(d_2) \\
d_1 &= \frac{\ln(\hat{s}_{i,0}/s_{i,0}) + 1/2v_i^2\tau_j}{v_i\sqrt{\tau_j}} \\
d_2 &= d_1 - v_i\sqrt{\tau_j}
\end{aligned}
\tag{5}
$$

where N is a normal cumulative density function and τ_j the time to maturity. The variance v_i^2 of $d(\hat{s}_i/s_i)/(\hat{s}_i/s_i)$ is:

$$v_i^2 = \sigma_{\hat{s}_i}^2 + \sigma_{s_i}^2 - 2\rho\sigma_{\hat{s}_i}\sigma_{s_i} \tag{6}$$

Margrabe (1978) has shown that the valuation formula for an exchange option can be rewritten as a traditional Black-Scholes formula for a call option where the underlying asset is the ratio between the two assets and the exercise price is equal to the unity. Eq. (5) can be rewritten accordingly

$$W_{i,0} = \left[\frac{\hat{s}_{i,0}}{s_{i,0}}N(d_1) - N(d_2)\right]s_{i,0} \tag{7}$$

where d_1 and d_2 are defined as in expression (5) and the variance of the underlying asset is v_i^2. [5]

This valuation formula is clearly based on the assumption that s_i and $\hat{s}_i$ follow a continuous Brownian motion. More recent studies analyzing the real options embedded in R&D projects have recognized that innovations emerge as a result of discontinuous jumps, which, consistent with earlier alternative models for the valuation of financial options (e.g. Merton, 1976), have been modeled as independent Poisson processes. In these models, the dynamics of the value of an innovation project is driven by a continuous Brownian motion and by the occurrence of abnormal variations (jumps) due to the stochastic arrival of new information with a Poisson distribution (see Willner, 1995 for an application to the value of startups; Brach & Paxson, 2001 for the valuation of new drug development projects). In particular, the model of Schwartz and Moon (2000) assumes that the value of an R&D project is governed by a standard Brownian motion, but that a catastrophic event suddenly driving the value of the project to zero can occur following an independent Poisson process.

Pennings and Lint (1997) have recognized that when the value of R&D is mainly driven by Poisson jumps, the Brownian motion that captures the continuous change in the value of the underlying asset can be disregarded. If in particular the jump amplitude is deterministic, the stochastic process of the underlying asset collapses to the 'pure jump' process described by Cox and Ross (1976) for financial options. Following this approach, the value of the underlying asset (present value of the expected cash flows from a given technology) does not change until an information shock arrives. In each period the expected number of information arrivals is assumed to follow a Poisson process with intensity λ.

This work is useful to redefine the stochastic processes of s_i and $\hat{s}_i$ in the valuation of the technology switching option defined in expressions (5) and (7). Assuming that the expected demand for firm i's products is equal for the two technologies,[6] we pose that the values of the existing and the new technology are equal at time 0 and that their evolution over time depends exclusively on the pattern of technological substitution. Following Arthur (1989), in this model technological substitution is driven by the process of technology adoption by the economic agents at the industry level and it is exogenous to the firm. Unexpected events, such as the arrival of scientific information on the new technology or a change in the political, institutional or legal context, can make the new technology more appealing to a larger fraction of potential adopters. Therefore, the arrival of an event shifts the value of the new technology relative to the existing technology. We assume that in industry j these events occur randomly following a Poisson process with intensity λ_j. Clearly, λ_j is equal for both s_i and $\hat{s}_i$ since any event affecting the value of $\hat{s}_i$ impacts also on the value of s_i. For example, a positive event (i.e., an industry-level agreement for the development of the new technological standard) should cause at the same time a negative jump in the value of the existing technology (s_i) and a positive jump in the value of the new technology ($\hat{s}_i$).

Based on the model of Pennings and Lint (1997), these assumptions allow to formulate the following stochastic processes for s_i and $\hat{s}_i$

$$
\begin{aligned}
s_{i,T} &= s_{i,t}\left[\Xi_{s,j} + 1\right] \\
\hat{s}_{i,T} &= \hat{s}_{i,t}\left[\Xi_{\hat{s},j} + 1\right]
\end{aligned}
\qquad (8)
$$

where $s_{i,T}$ and $\hat{s}_{i,T}$ are the present value of the expected cash flows from respectively the existing and the new technology after that new information has arrived, $s_{i,t}$ and $\hat{s}_{i,t}$ are the same values before information arrival. $\Xi_{s,j}$ and $\Xi_{\hat{s},j}$ are the jump amplitude in the value of s and $\hat{s}$ due to information arrival. In the model of Pennings and Lint (1997), the latter variable is calculated as follows:

$$\Xi_{k,j} = X_{k,j}\Gamma_{k,j}$$

with

$$X_{k,j} = \begin{Bmatrix} 1 & \text{with prob } p_{k,j} \\ -1 & \text{with prob } (1 - p_{k,j}) \end{Bmatrix}$$

$$\Gamma_{k,j} \big| X_{k,j} = \mathrm{Wei}(\gamma_{X,k,j}, 2)$$

and

$$k = s, \hat{s} \tag{9}$$

where $\mathrm{Wei}(\gamma_{X,k,j}, 2)$ is a Weibull distribution with shape parameter 2 (Rayleigh distribution) and $\gamma_{X,k,j}$ is the expected size of the jump conditional on $X_{k,j}$.

The absolute size of the jump ($\gamma_{X,k,j}$) should be equal for both s_i and $\hat{s}_i$ because when an event impacting on technology adoption occurs, the value gained by the new technology should be equal to the value lost by the existing technology. This is because a given fraction of technology users in industry j switches from the existing to the new technology. We can then state $\gamma_{X,s,j} = \gamma_{X,\hat{s},j} = \gamma_{X,j}$. Under the assumption of symmetric jumps ($p_{s,j} = p_{\hat{s},j} = p_j = 0.5$ and $\gamma_{1,j} = \gamma_{-1,j} = \gamma_j$), Pennings and Lint (1997) have shown that the variance of the underlying asset can be expressed as the product $\lambda_j \cdot \gamma_j^2$. Recalling that λ_j is equal for both s and $\hat{s}$, we have

$$\sigma_{\hat{s}_i}^2 = \sigma_{s_i}^2 = \lambda_j \gamma_j^2 \tag{10}$$

Moreover, since the existing and the new technology are alternative, the occurrence of a positive jump in the value of one of the two variables produces a negative jump of equal size in the value of the other variable. We have then $X_{\hat{s},j} = -X_{s,j}$. This means that the stochastic processes of s_i and $\hat{s}_i$ are perfectly negatively correlated ($\rho = -1$). Given expressions (6) and (10), the variance of the underlying asset $\hat{s}_i / s_i$ can be calculated as follows:

$$v_i^2 = 4 \times \lambda_j \gamma_j^2 \tag{11}$$

Eq. (11) clearly shows that the variance of the underlying asset of the technology switching option only depends on industry-level factors.

Firm's Probability of Innovation

When a new technology emerges, not all the firms can adopt it. The possibility to adopt depends, in fact, on the successful development of a process or product innovation based on the new technology before or at time τ_j. We then define $p_i(\tau_j)$ as the probability that a firm i successfully develops new processes and products based on the new technology at a time $t^* \leq \tau_j$. Following previous literature on R&D races (Loury, 1979; Lee & Wilde, 1980; Reinganum, 1983), the probability $p_i(\tau_j)$ is assumed to have an exponential distribution, so that it can be calculated as follows:

$$p_i(\tau_j) = p\{t^* \leq \tau_j\} = 1 - \exp(-\lambda_i \tau_j) \tag{12}$$

where $1-\exp(-\lambda_i\tau_j)$ is the exponential cumulative density function and λ_i is firm i's hazard rate.

The probability $p_i(\tau_j)$ is assumed to be independent from the stochastic processes of s_i and $\hat{s}_i$. In fact, whereas the former depends on the firm-specific hazard rate (λ_i), the latter are related to industry-level variables (λ_j and γ_j). This means that the stochastic process underlying the value of the technology does not depend on the stochastic process governing the achievement of a successful process and product innovation at the firm level.[7] Under this assumption the probability $p_i(\tau_j)$ and the technology switching option can be evaluated independently.

In the spirit of the literature on R&D races, we decided to link the hazard rate to the firm-specific innovation effort relative to industry-level overall innovation effort. To this purpose, we assumed that the hazard rate λ_i is a function of the ratio between firm i's R&D investments at time 0 ($R_{i,0}$) and industry total R&D investments at time 0 (R_0), which we define as *R&D share.*[8] A higher R&D share indicates that a firm is more likely to exercise the technology switching option in the case this will prove to be valuable. Thus, given the estimated value of $W_{i,0}$, the market valuation of the technology switching option should increase with its probability of exercise. In other words, a firm could have high $W_{i,0}$ because of high technological uncertainty in the industry, but the stock market could evaluate it poorly if the firm has a low probability to adopt the new potential technology due to a low R&D share. We would then expect the following:

H2. The stock market will place a higher valuation on the technology switching option of those firms having a higher probability to adopt the new technology.

DATA AND VARIABLES

Sample

The initial sample we created consisted of a panel of 250 R&D-doing manufacturing companies publicly traded in the United Kingdom from 1989 to 1998. The choice of this country was due to several reasons: the relatively large size of the stock market; the R&D accounting regime, requiring the firm to disclose R&D investments in their financial statements, different from other European countries (such as France, Germany and Italy);[9] the only recent attention to the market valuation of R&D investments as compared to the United States.[10]

In the original database we retained only those companies for which data were available for at least three continuous years. We then classified the firms into 24 different industries by SIC 1992 code, based on the classifications defined and used in previous studies (Hall & Vopel, 1996; Oriani & Sobrero, 2002; Hall & Oriani, 2006). The source for accounting figures and market capitalization at the firm level was Datastream International, which has a full coverage of publicly traded British firms (including information for dead stocks).

In order to calculate the present value of the expected cash flows ($s_{i,0}$), which represents the underlying asset of the technology switching option, we had to integrate this database with data on financial analysts' forecasts, as we explain later in this section. In particular, following Berger et al. (1996), we referred to the data on analysts' consensus estimates provided by IBES, which includes analyst data on over 18,000 companies in 60 different countries. IBES summary history consists of chronological snapshots of consensus level data taken on a monthly basis. Forecast measures include items such as earnings per share, cash flow per share (CPS), net income, EBITDA, long-term growth. Nevertheless, IBES forecast data availability for the companies traded in the UK was limited in several ways as compared to the data originally gathered from Datastream. In fact, earnings per share and CPS forecasts were reported only from 1993 and just for a part of the companies included in the original sample. Moreover, we retained only those observations for which cash flow forecasts were available for at least the three following years. In the end, we were able to create an unbalanced panel of 85 firms and 319 observations in 15 different industries from 1993 to 1998 (see Table 1).

Table 1. Firms and Observations by Industry.

Industry	Firms	Observations	Percentage (%)
Food	12	52	15.5
Textile	2	6	1.8
Chemicals	14	60	17.9
Oil	7	32	9.5
Building materials	4	16	4.8
Primary metals	2	8	2.4
Refined metals	2	8	2.4
Machinery	8	26	7.7
Electrical	4	15	4.5
Electronics	6	20	5.9
Aerospace	3	12	3.6
Motor vehicles	8	23	6.8
Scientific instruments	6	18	5.4
Pharmaceuticals	6	29	8.6
Utilities	3	11	3.3
Total	87	336	100.0

Firm-Level Variables

The total market value of the firm ($V_{i,0}$) should be calculated as the sum of the market capitalization and the market value of debt. However, data on the market value of debt are often not available. Some of the studies on US samples tried to define proxies for the market value of debt using data on corporate bond market (Hall, 1990). This solution was not feasible for European samples because of the limited development of corporate bond markets. Therefore, according to previous similar analyses on UK data (Blundell, Bond, Devereux, & Schiantarelli, 1992; Blundell et al., 1999), we calculated the market value of the firm adding the value of outstanding debt to the market capitalization observed the last trading day of the year.

The capital of technological knowledge ($K_{i,0}$) was computed as a perpetual inventory of the past R&D expenditures with a constant 15% depreciation rate, as done by several previous analyses applying hedonic method (e.g. Jaffe, 1986; Cockburn & Griliches, 1988; Hall, 1993a, 1993b; Hall & Oriani, 2006) and described in detail by Griliches and Mairesse (1984) and Hall (1990). The capitalization of R&D investments was needed because annual R&D costs are not capitalized in the balance sheet, but they are normally expensed in the P&L accounts when they occur.[11]

In our regression models we also included several variables to account for specific effects that could affect corporate value. At the firm level, we considered the other intangible assets of the firm ($I_{i,0}$), mainly consisting of trademarks and goodwill, divided by total tangible assets ($A_{i,0}$). The inclusion of this variable was necessary in order to explain that part of Tobin's q related to non-R&D intangibles. Furthermore, we added a full set of year dummies to control for all other time-specific effects.

The Valuation of the Technology Switching Option

One of the most complicated tasks in testing real options theory is the definition and the assessment of the option parameters. According to (5) and (11), in order to calculate $W_{i,0}$, we needed measures for $s_{i,0}$, which was assumed to be equal to $\hat{s}_{i,0}$, v_i^2 and τ_j.

With respect to $s_{i,0}$, we calculated a proxy of the present value of a firm's expected cash flows following the approach of Berger et al. (1996):

$$s_{i,0} = \sum_{t=1}^{n} \frac{\mathrm{CF}_{i,t}}{(1+r_i)^t} + \frac{\mathrm{PVCF}_i}{(1+r_i)^n} - \mathrm{CAPEX}_i - \mathrm{WCG}_i \qquad (13)$$

where $\mathrm{CF}_{i,t}$ is firm i's expected cash flow at year t, PVCF_i the present value of the firm i's expected cash flows after year n, CAPEX_i the present value of firm i's future capital expenditures, WCG_i the present value of firm i's expected investments in net working capital and r_i firm i's CAPM return, calculated as explained below. These variables were calculated referring to financial analysts' estimates. The use of analysts' data to assess a firm's value has been validated by Kaplan and Ruback (1995). We gathered the information on analysts' forecasts from the IBES consensus estimates data file. Since IBES reports explicit cash flow forecasts only for the 3 years following the observation year, we fixed n equal to 3 years.[12]

For each firm in our original sample we picked, when available, the estimation made at the end of year 0 of the operating CPS for year 1 (CPS1), year 2 (CPS2) and year 3 (CPS3). The measure of CPS calculated by IBES is the cash flow from operations, before investing and financing activities divided by the weighted average number of common shares outstanding in the year of the estimation. We completed this information with the number of outstanding shares ($\mathrm{NS}_{i,t}$) that the selected companies had at the end of each year in the sample. Finally, as mentioned above, we retained only those observations for which CPS1, CPS2, CPS3 and NS were reported in the

IBES consensus estimates data file. We had $CF_{i,1} = CPS1 \times NS_{i,1}$, $CF_{i,2} = CPS2 \times NS_{i,2}$ and $CF3_{i,3} = CPS3 \times NS_{i,3}$.

We then calculated the present value of the cash flows after year 3 ($PVCF_i$). To this purpose, we discounted the last cash flow as a perpetual rent with a constant growth rate. The growth rate of the nominal cash flows should reflect the expected inflation rate. Assuming a zero real growth rate in the long term, we set the growth rate equal to the implied inflation rate of the 10-years UK Government Bonds at the end of each year as reported by the Bank of England.

However, our calculation of the cash flows did not include yet the outflows related to the investment in capital assets and working capital. Unfortunately, IBES does not provide forecast data on these items. One possible solution was to develop forecasts from historical figures, but the variations over time in capital expenditures and working capital can lead to overestimate these flows in some years and underestimate them in other years. Therefore, we followed the approach adopted by Berger et al. (1996), who subtracted from discounted cash flows a fixed percentage representing the expected excess capital expenditures and working capital increases. This percentage was calculated as the ratio of excess capital expenditures and working capital growth to the market value of equity. They had a median deduction of 12% for excess capital expenditures and 5.5% for working capital expenditures.[13] We used these values to calculate the present value of capital expenditures ($CAPEX_i$) and working capital growth (WCG_i) for all the observations in our sample. In order to be conservative and not to overestimate the value of $s_{i,0}$, we multiplied the previous ratios not for the market value of the firm's equity, but for the enterprise value (V_i), whose calculation has been explained in the previous section.

Finally, we had to determine the cost of capital (r_i) to discount the expected cash flows. In this respect, we referred to the traditional CAPM method. We have then $r_i = r_f + \beta_i\,(r_m - r_f)$, where r_f is the risk-free interest rate, $(r_m - r_f)$ is the stock market risk premium and β_i measures systematic risk. Following a conventional approach, r_f was assumed equal to the interest rate on 3-month UK Treasury Bills registered at the end of each year in the sample and retrieved from the Bank of England. The stock market risk premium was set equal to 4.5% according to the estimation provided by Damodaran (www.damodaran.com) and by the historical analysis of Dimson, Marsh, and Staunton (2002) for the UK stock market.[14] β_i was calculated for each firm and year as the slope of a straight line fitted to 156 observations of weekly relative price changes (3 years) obtained from Datastream. In particular, the weekly percent price change in a particular stock was regressed on the weekly percent change of the FTSE all-share, which is the index including all the stocks traded on the London Stock Exchange, applying ordinary least squares. Please note that similarly to Berger et al. (1996) we use the discount rate of an all-equity firm, ignoring the tax shield of debt. This choice is due to several reasons. First, the difficulty of determining the objective financial structure of the firm, which is needed to calculate the present value of the tax shield. Second, the value of tax shield is uncertain and often limited by several factors. Therefore, using a discount rate of a pure equity firm should lead to a more prudential estimation of the value of the underlying asset.

The other variables to be estimated are the variance v_i^2, which as explained in the previous section is equal to $4 \times \lambda_j \gamma_j^2$, and the time to maturity τ_j. Lint and Pennings (2001) suggest that the parameter λ_j can be estimated as the ratio between the number of events in the entire period and the number of years the period lasts. In order to simplify the calculation of this ratio, we assumed that one critical event in the period of interest will make the new technology more valuable than the existing one. This assumption is consistent with the model of Schwartz and Moon (2000), where one critical event occurring as a Poisson jump over the life of an R&D project can catastrophically impact on its value.

We then needed an estimation of the period of interest. In our model the period is equal to τ_j, which is the time to maturity of the option. In the model described in the previous section, τ_j has been defined as the time after which technology adoption would have no longer effect on firms' expected profits. It had also been considered exogenous to the firm. Therefore, in order to calculate λ_j, we have to calculate τ_j. We decided to use patent citations at industry-level to measure τ_j. Each patent normally cites previous patents that represent the prior state of the art. Data on patent citations have been used in a series of empirical works (Jaffe & Trajtenberg, 2002).

In this respect, the main operational problem concerned the identification of the patents and the correspondence between industrial classification and patent technological classification. In fact, while the SIC classification is application oriented, technological classifications, such as IPC, are normally function oriented, so that technological classes do not match to industry groups. In order to overcome this problem, we selected the patents belonging to the firms that constitute the Tech-Line® sample created by CHI Research, including all the patents granted by the USPTO to the worldwide top patenting firms and institutions (see Narin, 1999 for further details on the sample constituents).[15] We eliminated Universities and public research centers from the original sample, so to retain only private companies. We then reclassified these companies by SIC92 code, in order to have a classification consistent with our firm-level database. We eliminated those conglomerate corporations that could not be assigned to a specific industry. In the end, we attributed all the patents granted from 1993 to 1998 in the Tech-Line sample to the industries of their assignee (see Oriani & Sobrero, 2002 for details).

The indicator we adopted is the Technology Cycle Time (TCT), defined and calculated by CHI Research (see Narin, 1999) and empirically validated by several studies (e.g. Kayal & Waters, 1999). This is computed as the median age in years of the US patent references cited on the front page of the patent. When calculated at industry level, it captures some elements of the *rapidity of the technology cycle* in that industry since it measures the time between the previous patents upon which current patents are improving and the current patents (Narin, 1999). Accordingly, companies operating in an industry with a shorter technology cycle have to switch more often from the existing to a new technology. The average TCT by industry is reported in Fig. 1. It is possible to notice that the pharmaceutical, scientific instruments and electronics industries have much shorter technology cycles (between 6 and 7 years) than the other industries. On the contrary, the industry of refined metals has the longest technology cycle (~13 years).

For each industry and year in the sample, we set τ_j equal to the average TCT calculated at the industry level. The idea is that an innovation occurring after the current technology cycle has no economic value because the technological progress has made it obsolete. Accordingly, we also set $\lambda_j = 1/\tau_j = 1/\mathrm{TCT}$.[16]

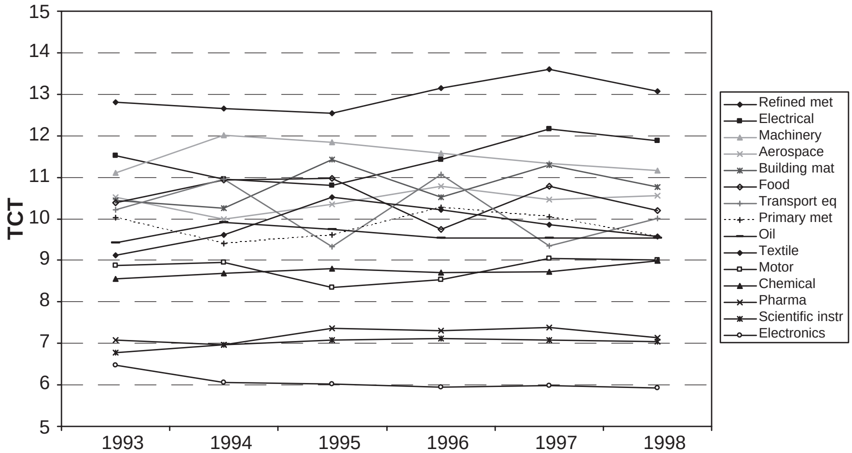

Fig. 1. Technology Cycle Time (TCT) by Industry and Year.

Finally, in order to calculate v_i^2, a proxy for γ_j was needed. This variable should measure the expected size of the value shift of s_i and $\hat{s}_i$ conditional on the arrival of an event. As we have assumed in the previous section that the stochastic process of s_i and $\hat{s}_i$ depends on the pattern of technological substitution in the industry, γ_j should be related to the industry-level rate of technological substitution. Therefore, we measured this variable for each year and industry as the ratio between the new patents granted in that industry in a given year and the industry-level stock of patents in the previous year. In those industries with a higher technological substitution rate, the existing stock of patents should be renewed more intensely by the release of new patents. Also in this case we referred to the patents of the Tech-Line database assigned to the industries in our sample as explained above. The patent stock was calculated using the well-known perpetual inventory formula with a constant 15% depreciation rate adopted by several studies to capitalize patents both at the firm-level (e.g. Hall, Jaffe, & Trajtenberg, 2005) and the industry-level (e.g. Shea, 1998):

$$K_{j,t} = K_{j,t-1}\,(1 - 0.15) + P_{j,t} \tag{14}$$

where $K_{j,t}$ is the stock of patents in industry j at time t and $P_{j,t}$ the number of new patents granted in industry j at time t.[17] Accordingly, for each industry j and year t, γ_j was defined as the ratio $P_{j,t}/K_{j,t-1}$.

Probability of Innovation

Finally, we had to calculate the probability $p_i(\tau_j)$ defined in expression (12). In particular, we needed to measure the firm-specific hazard rate λ_i, since τ_j has already been calculated. As said above, the hazard rate depends on the firm's R&D share, which is the ratio between a firm's R&D investments and total industry R&D investments. In order to calculate this ratio, firm's annual R&D expenditures were drawn from Datastream, whereas industry total R&D expenditures were gathered from the ANBERD database released by the OECD.

Descriptive Statistics

Having defined $s_{i,0}$, v_i^2 and τ_j, we calculated $W_{i,0}$ for any observation based on expressions (5) and (7). We excluded the observations presenting a negative value of $s_{i,0}$. The average value $W_{i,0}$ scaled by total tangible assets (A)

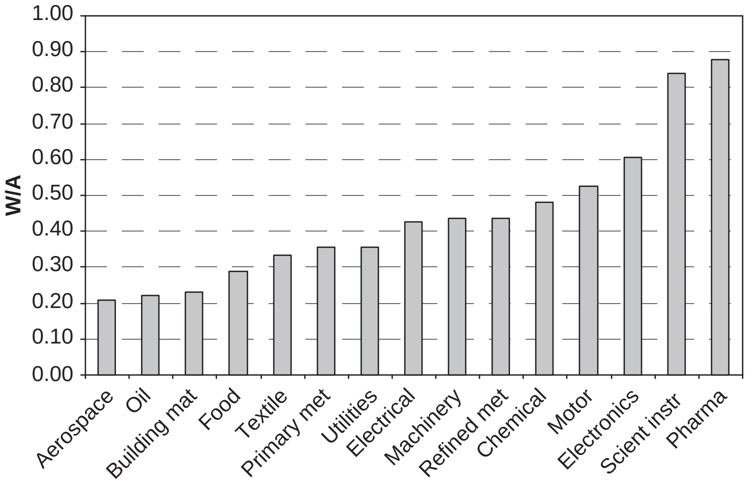

Fig. 2. Average W/A Ratio by Industry.

Table 2. Observations, Mean, Standard Deviation, Median, Minimum and Maximum of the Variables Included in the Regression.

Variable	Observations	Mean	Standard Deviation	Minimum	Median	Maximum
V/A	336	2.455	1.825	.542	1.843	13.491
K/A	336	.227	.277	.006	.125	1.671
I/A	336	.223	.446	0	.001	2.431
W/A	336	.453	.359	.033	.364	3.801
P	336	.447	.364	0	.35	1

by industry is shown in Fig. 2. The average ratio $W_{i,0}/A_{i,0}$ is much larger in the pharmaceutical and scientific instruments industry, where its value is above the 80% of total tangible assets. Moreover, it is higher than 60% of the total tangible assets in the electronics industry and ~50% in the chemical and the motor industry.

The descriptive statistics of the variables, including mean, standard deviation, median, minimum and maximum values, are shown in Table 2. In Table 3 we report the correlations between the variables. $W_{i,0}/A_{i,0}$ is positively correlated to both $K_{i,0}/A_{i,0}$ (.24) and $I_{i,0}/A_{i,0}$ (.22). As expected, there also exists a positive correlation between p_i and $K_{i,0}/A_{i,0}$ (.32). However, none of these correlation coefficients should raise serious concerns about multicollinearity.

Table 3. Correlations between the Variables Included in the Regression.

	$V_{i,0}/A_{i,0}$	$K_{i,0}/A_{i,0}$	$I_{i,0}/A_{i,0}$	$W_{i,0}/A_{i,0}$	p_i
$V_{i,0}/A_{i,0}$	1.00				
$K_{i,0}/A_{i,0}$	.48***	1.00			
$I_{i,0}/A_{i,0}$	.44***	.24***	1.00		
$W_{i,0}/A_{i,0}$	.52***	.24***	.22***	1.00	
p_i	.04	.32***	.05	−.28***	1.00

***$p<.01$.

Table 4. Results of the NLLS Estimation of Eq. (4).

	(1)	(2)	(3)
Constant	.34***	.06	.10
	(.09)	(.08)	(.09)
K/A	1.17***	.71***	.50***
	(.22)	(.15)	(.16)
I/A	.65***	.45***	.40***
	(.13)	(.09)	(.09)
W/A		.72***	.62***
		(.06)	(.08)
$W/A \times p$			.73***
			(.21)
p			−.21**
			(.10)
Year dummies	Yes	Yes	Yes
Observations	336	336	336
Adjusted R^2	.2882	.4828	.4994
F (Delta R^2)	–	123.03***	5.39***

Standard error in parentheses. Dependent variable: ln (V/A).
**$p<.05$.
***$p<.01$.

RESULTS

Eq. (4) has been estimated through *non-linear least squares* (NLLS), as done by recent empirical work on innovation and market value (Bloom & Van Reenen, 2002; Oriani & Sobrero, 2002; Hall et al., 2005; Hall & Oriani, 2006).[18] The results are reported in Table 4. We first estimated the basic version of the hedonic model, without including the technology switching option (model 1). The coefficients of K/A (1.17) and I/A (.65) are both positive and statistically significant at the 1% level. Moreover, these results are very close to those obtained by Hall and Oriani (2006) for a broader UK sample. This means that the stock market positively evaluates these assets. In model 2 we include the technology switching option scaled by total tangible assets (W/A) according to Eq. (4). The coefficient of W/A is positive (.72) and statistically significant at the 1% level, supporting H1. Note also the increase in the adjusted R^2, passing from .2882 in model 1 to .4828 in model 2. The F test performed on the difference between the adjusted R^2 confirms that the difference is statistically significant at the 1% level. Thus, the inclusion of the technology switching option in the regression equation considerably improves the fit of the regression. Moreover, as expected the coefficient κ shrinks from 1.17 (model 1) to .71 (model 2) due to the inclusion of W in the right-hand side of the regression equation. This is due to the fact that in model 2 the value of uncertain innovation should be captured by the technology switching option. In practice, separating the effects of K and W adds information on the effect of innovation on the market of value of the firm.

In model 3, we introduce the probability p_i, as defined in Eq. (12), and its interaction with W/A. The coefficient of the product $p_i \times W/A$ is positive (.73) and statistically significant at the 1% level, confirming the prediction of H2. The coefficient of the stand-alone effect of W/A is still positive (.62) and statistically significant at the 1% level. The coefficients of K/A and I/A remain positive (.50 and .40, respectively) and statistically significant at the 1% level. The increase in the adjusted R^2 is modest (from .4828 to .4994), even though the F test indicates that the difference is still statistically significant at the 1% level. The negative and significant stand-alone coefficient of p ($-.21$) suggests that the stock market positively evaluates a higher probability to adopt a new potential technology only if the technology switching option is valuable. For low values of W, in fact, a greater R&D effort reflected into higher p would have a negative effect on firm market value.

DISCUSSION AND CONCLUSIONS

Methods for a better evaluation of innovation investments are more necessary as these investments become critical for the competition among firms. Real options theory has provided very useful insights into this problem, but its practical application has been hindered by several problems (Lander & Pinches, 1998; Luehrman, 1998; Copeland & Tufano, 2004). First, it is hard to define the valuation parameters because the real projects to be evaluated are not traded assets. Second, the theory still lacks a robust empirical validation. Some studies have adopted a real options logic in the analysis of the stock market valuation of firms' technological knowledge (Bloom & Van Reenen, 2002; Oriani & Sobrero, 2002; de Andrés Alonso et al., 2005; Reuer & Tong, 2007b), but they have not formalized specific real options associated with firms' R&D investments.

This paper addressed this shortcoming through the modeling and the valuation of a technology switching option and its inclusion within a testable market value equation. It also defined new measures of the option parameters needed for the valuation. To this purpose, indicators of technology uncertainty were built on industry-level patent data. Moreover, different from previous models, this paper also tried to account for the stochastic nature of innovation, linking the firm's probability to innovate to its R&D investments.

The results of the empirical analysis support the claim that the stock market recognizes and evaluates accordingly a technology switching option. The remarkable improvement in the regression fit after including the switching option suggests that the explicit valuation of this option adds relevant information on the determinants of a firm's market value. Moreover, the market valuation implies that a greater R&D share, positively affecting a firm's probability to innovate, increases the value of the technology switching option. This latter result is in line with the theoretical works on R&D competition, which, however, with the exception of the study of Cockburn and Henderson (1994), has received scarce empirical validation.

The main contribution of this paper consists therefore in the effort to evaluate a specific real option and to test whether this is reflected into the firm market value, in the spirit of the work of Berger et al. (1996). In particular, the analysis conducted in this paper can offer several useful insights into the existing literature on innovation and real options, as well to managers and financial analysts. First, it formalizes the value of a technology switching options that had already been individuated by previous theoretical contributions (e.g. McGrath, 1997; Miller, 2002). Second, the validation of a closed form of this option within a cross-industry empirical setting can provide financial analysts with the basis for more sophisticated models to assess a firm's market value. Third, the results empirically support the predictive power of a valuation method based on real options theory. In this way it proposes to managers a new tool for the assessment of innovation strategies.

Finally, it is noteworthy to remark the limitations of this paper, which also represent potential fruitful avenues for future research. First, in some industries firms may simultaneously develop several product and process technologies. A firm would then possess not a single switching option, but a portfolio of switching options (see Vassolo et al., 2004; Anand et al., 2007). Thus, a more precise formalization of the switching option would require an analysis at the level of the technology. However, this is extremely difficult within a cross-industry setting. This suggests at least two possible solutions. Without loss of generality, building on previous studies on the relationship between patent's and firm's market value (e.g. Hall et al., 2005), it is possible to model a portfolio of options using firm-level patent data (see, for example, Chi & Levitas, 2007). Alternatively, limiting the focus on a specific industry, it can be insightful to study the determinants of the value of the technology switching option (for example, switching costs) more in depth. Further steps into these directions could shed new light on the innovation-related value creation processes and provide practitioners with more refined valuation methods of a firm's innovation investments.

Second, technology switching option could coexist with other types of real options within a firm's option portfolio (Anand et al., 2007). In this paper we tried to measure the value of this specific option, controlling for the value of other potential real options through the inclusion of different variables (R&D capital and other intangible assets). A deeper comprehension of the value of a firm's real options could require, however, calculating the values of other real options and incorporate them into a market value equation, also because there could be significant interaction effects among the value of real options within projects (Trigeorgis, 1993) and across projects (Vassolo et al., 2004; Anand et al., 2007). Notwithstanding these limitations, we believe, in line with other studies focusing on different types of real options (e.g. Berger et al., 1996; Reuer & Tong, 2007a), that testing the association between a real option and firm market value can contribute to the empirical validation of real options theory and to its potential implementation.

NOTES

1. Please refer to Reuer and Tong (2007b) for a review of these studies.

2. The underlying assumption is that in the future the firm will continue to invest in A and K according to the rule of optimal profit maximization (see Hall, 1993b, Appendix A, for a formal treatment).

3. See Hall (2000), Oriani and Sobrero (2003) and Czarnitzki, Hall, and Oriani (2006) for a review of these models.

4. The technology could be adopted also before time τ. We are assuming however that the adoption can occur at time τ in order to have a close valuation formula for

the technology switch option (see the discussion below on the choice of the option valuation formula).

5. Please note that this formula does not include switching costs, i.e., the costs to switch from one asset to the other. Switching costs can be important in the case of the technology switch options because the adoption of a new technology could imply several costs of different nature for the organization. However, although introducing switching costs in the model would be straightforward (they would be subtracted from the value of the new technology), we decided not to include them since it would be very hard to have a reliable estimation of their value for a broad cross-industry sample in the empirical analysis.

6. This assumption is excluding market uncertainty from the valuation of the technology switch option. Market uncertainty can be relevant in the market valuation of R&D investments (see Oriani & Sobrero, 2002). Thus, the model presented here has an important limitation, which is justified by its specific interest on the role of technological uncertainty.

7. In a similar fashion, Weeds (2002) separates the uncertainty concerning the future profitability of the technology from the technical uncertainty over the success of the R&D investment.

8. Similarly, Darby, Liu, and Zucker (1999) assume that the probability of innovation by firms in the biotechnology industry is a linear function of the firm's human capital, represented by the number of ties to star scientists.

9. See Belcher (1996) on this point.

10. Remarkable exceptions are: Green, Stark, and Thomas (1996), Blundell et al. (1999), Toivanen, Stoneman, and Bosworth (2002), Oriani and Sobrero (2002), Hall and Oriani (2006).

11. These conditions are consistent with the prescription of US GAAP and IAS accounting standards that allow some costs related to R&D activities to be appropriately capitalized and carried forward as assets only if they have alternative future uses (see for example, Lev & Sougiannis, 1996).

12. As done by Berger et al. (1996), we tried to extend the cash flow forecast to 5 and 10 years using the expected long-term growth rate estimated by analysts and reported by IBES. However, in order to have a more conservative estimation, we preferred to rely on the explicit cash flow forecast reported for the first 3 years.

13. Berger et al. (1996) grouped the observations drawn from the Compustat database into deciles of the historical levels of both excess capital expenditures and expected working capital growth. Then, for each observation, they adjusted the present value of expected earnings by a fixed percentage accounting for future excess capital expenditures and working capital growth depending on the decile rankings of the specific observation. Our data did not allow us to define decile rankings with the precision that was allowed by Compustat. For this reason, we preferred to subtract the same percentage from all the observations.

14. Damodaran first estimates the market risk premium for the United States based upon a two-stage dividend discount model. The estimation reflects the risk premium that would justify the current level of the index, given the dividend yield, expected growth in earnings and the level of the long-term bond rate. After that, he estimates the market risk premium for the other countries using the country ratings assigned by Standard and Poors'. The market risk premium for the UK is equal to

the market risk premium estimated for the US. An equal estimate is provided by Dimson et al. (2002) through the historical analysis of the UK stock market returns for a 100-years period.

15. Patent assignees are consolidated at corporate level by CHI Research. Moreover, when M&A operations occur, the patents are automatically reassigned to the acquiring company.

16. The use of the TCT indicator to calculate both λ_j and the time to maturity of the technology switch option allows us to address empirically the potential ambiguity of the effect that the length of the technology cycle has on the value of the option. In fact, a higher TCT increases the time to maturity of the option, which is a positive element of the option value, but, ceteris paribus, it decreases the variance, reducing the option value.

17. Following standard practice (e.g. Hall et al., 2005), the initial stock of patents was calculated in 1986 dividing the number of patents granted in 1986 by the sum of the depreciation rate (15%) and a constant patent growth rate of 8%.

18. These studies adopted a repeated cross-section approach. Indeed, the recent study of Hall and Oriani (2006) showed that the inclusion of firm-specific effects through panel estimation techniques does not remarkably affect the results.

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STRATEGIC IMPLICATIONS OF VALUATION: EVIDENCE FROM VALUING GROWTH OPTIONS

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ABSTRACT

Strategy is ultimately aimed at creating shareholder value. We examine the relationship among intrinsic (DCF) value, market value, and the value of growth options using a "perfect foresight" model. Our findings suggest that Kester's (1984) initial assessment of growth option values may not hold under alternative valuation models. We highlight important issues in the valuation of growth options related to market expectations, modeling assumptions and estimation methods. The findings suggest that the firm's growth option value depends on three factors, each of which impacts investor expectations: (1) the macroeconomic environment; (2) the industry in which the firm participates; and (3) firm specific factors.

The asset valuation process represents a key stage in the allocation of resources (Bower, 1970; Noda & Bower, 1996). The resulting valuations are critical inputs to strategic decision-making (Folta & Miller, 2002; Robins, 1992; Varaiya, Kerin, & Weeks, 1987). Myers (1984) noted both the

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convergence and the divergence between finance and strategy, and developed forceful arguments that finance theory and strategic management need to be reconciled. Similarly, Bettis (1983) noted that, while often at odds on objectives and methods, finance theory and strategic management were pursuing many of the same issues, and so also argued for a reconciliation of the two fields.

Both Myers (1984) and Bettis (1983) saw the role of valuation as an important linkage, or bridge, between finance and strategy – strategy concerned with allocating firm resources in order to achieve a competitive advantage, finance concerned with allocating firm resources in order to increase shareholder wealth. Myers (1984) pointed out, "This would seem to invite the application of finance theory, which explains how real and financial assets are valued. The theory should have direct application not only to capital budgeting, but also to the financial side of strategic planning" (p. 128). In other words, how can we logically make strategic decisions without some understanding of how they will ultimately impact firm value? In fact, the value of the firm, as determined by market participants, is a critical indicator, if not the most critical indicator, of strategic effectiveness (McTaggert, Kontes, & Mankins, 1994; Rappaport, 1998; Varaiya et al., 1987). Hence, it is essential to understand how specific strategic decisions will ultimately impact firm value, although measuring the value created or destroyed may be a difficult process (Zingales, 2000).

Scholars in the real options literature have highlighted the important role of valuation, demonstrating that the valuation approaches employed by firms have strong implications for strategic managers. For example, the use of an options approach can lead to different investment decisions than a discounted cash flow (DCF) approach, as highlighted by early real options contributions (e.g. Baldwin & Clark, 1992; Dixit & Pindyck, 1994; Luehrman, 1998; Trigeorgis, 1996). Not only can different valuation approaches yield different estimates of investment value, but even varying assumptions and estimation methods within the same approach can lead to different investment decisions.

Myers (1977) and Kester (1984) provided early arguments to support both the existence of real option value, in the form of growth opportunities or growth options, and the impact of differing valuation models and assumptions. Myers (1977) states that the value of growth opportunities depends upon further discretionary investment and, according to Kester (1984), "companies can reduce the guess work of investment analysis by clearly linking current capital budgeting decisions with strategic opportunities" (p. 153). Based on large-scale field research, Kester determined managers often argue that an inadequate valuation must be weighed against the "strategic benefits" of an investment project, such as the future opportunities the project will create for the firm. Kester (1984) and Myers (1984), however, noted that these growth options cannot be valued using a traditional DCF – net present value (NPV) – analysis. Kester (1984) argued that these "growth options" are analogous to, and, therefore, can be valued similarly to, financial call options.

Kester (1984) roughly estimated the value of the growth option components of the market values of equity[1] of a sample of 15 firms – 3 in each of 5 industries – and showed that the value of a firm's growth options often account for a large part of total firm value. He modeled the value of a firm's growth options as equal to the firm's current market value less the value of a perpetuity of the firm's current annual (1983) earnings capitalized at 15, 20, or 25%. The capitalized earnings represent an estimate of the value of the assets already in place. The growth option values thus calculated ranged from 7% to 88% of firm market values, depending on the particular firm and discount rate used. This suggests that the value of growth options accounts for a substantial and in some cases dominant portion of the market value of typical firms. Furthermore, Kester found that the growth option value component of a firm's market value appeared to vary with industry. Kester's study, while enormously influential in terms of its implications, suffers from a very small sample size and a relatively simplistic valuation model. These are shortcomings that the current paper aims to address while further exploring strategic issues related to valuation assumptions and models.

Building an empirical understanding of the relationship between real options and DCF valuation is an important step in tying strategy to shareholder wealth creation. Kester's (1984) approach serves as a foundation for the examination of the predictive ability of DCF models and their relationship with growth options. This research revisits Kester's (1984) findings, investigating the role of growth options in explaining and empirically examining, from a strategic point of view, the relationship between the market value of a firm and its DCF, or "intrinsic," value.[2] We also extend Kester's (1984) approach to a larger and more rigorous empirical assessment and practical multi-year DCF valuation model. Rather than rely on ex ante estimates of value, we conduct our analysis from the perspective of "perfect foresight," where the investor has knowledge of actual cash flows and other required model inputs. In other words, how does the actual market value of the firm on a given date, such as January 1, 1989, compare to the intrinsic value of the firm on the same date according to a DCF valuation when using completely accurate "forecasts" of cash flows and discount rates?

The majority of firms continue to rely on DCF models in their corporate capital budgeting practices (Graham & Harvey, 2001). Our paper highlights important issues in the predictive ability of DCF models and market expectations, and their relationship with three critical factors–economic conditions, industry membership, and firm specific capabilities. Our findings highlight the difficulty of accurately assessing the value of a firm's growth opportunities (Zingales, 2000), and how varying modeling assumptions and estimation methods can strongly impact resulting intrinsic value. Given the link between valuation and strategic decisions, this study raises important questions concerning the use of DCF models in the capital budgeting practices of firms. Strategy has been portrayed as the result of iterations of the resource allocation process (Noda & Bower, 1996). Issues in the valuation process can have a strong influence on the firm's strategy through affecting strategic investment decisions and the allocation of resources. The competitive consequences of "incorrect" choices can be potentially serious, as discussed by Christensen and Bower (1996).

The next section reviews the DCF framework and its ability to account for the value of corporate growth options. We also briefly highlight the connection between DCF and real options frameworks in the context of growth options. We continue by presenting our replication and extension of Kester's (1984) tests in a three-phase approach. The first phase employs Kester's (1984) model using a larger sample and more current earnings data. Phase two again involves the use of a larger sample size but also of a different source of value – cash flow instead of earnings. Finally, the third phase extends Kester's work, detailing a more sophisticated DCF model used to conduct further tests of Kester's (1984) findings, including various sensitivity analyses. We combine the presentation of phases one and two since they rely on the same valuation model with different inputs. We conclude with implications for both current research and business practices, as well as for future research.

VALUATION FRAMEWORKS

Today, few would argue that one key to an effective strategy is the allocation of firm resources – tangible and intangible – so as to achieve a competitive advantage. Often these allocation decisions are made in the context of capital budgeting, and this is especially true of tangible assets. In fact, it could be argued that for a wide range of resources, allocations should be made through capital budgeting informed by strategy or, as some would put it, strategy informed by capital budgeting. Which comes first in the grammatical construction is irrelevant – both are intertwined and critical to resource allocation decision-making.

For example, consider a formal "project," since many, if not most, resource allocation decisions appear in the form of some sort of formal project: a new plant, the exit from a product line, a market entry, a firm acquisition, a new service location. In fact *a firm can be conceptualized as a collection of projects* (Zingales, 2000). This view of the firm as a collection of projects, some of which may not be formally viewed as such by managers in the firm, is common in the finance literature (e.g., see Brealey & Myers, 1996). For purposes of the current paper, this view allows the results obtained at the firm level to also be applicable at the project level.

The traditional and widely used valuation framework for analyzing projects is a DCF analysis, which is used to determine a project's NPV. Such an analysis requires, as inputs to project valuation, the cash flows the project will generate, the economic life or forecast period over which these cash flows will occur, any terminal value (net salvage value or residual value), and, finally, the project's risk-adjusted discount rate. The appropriate discount rate for such an analysis is the project's opportunity cost of capital. It is reflective of the project cash flows' risk and timing, and is theoretically defined as the expected rate of return, in equilibrium, of an efficient market-traded security of equivalent risk class as the project. Because of the difficulty in finding such a rate of return, in practice, the cost of capital of the firm as a whole may be used, even though it is not theoretically correct to do so unless the project has the same risk as the firm as a whole.

Myers (1984), Baldwin and Clark (1992), Dixit and Pindyck (1994), Trigeorgis (1996), Amram and Kulatilaka (1999), and others, have detailed the troublesome assumptions and valuation issues of the traditional DCF valuation framework. For example, a traditional DCF analysis assumes passive management of the investment, an "all-or-nothing" valuation, a fully reversible investment, a "now or never" decision, and a reduction in value due to uncertainty. Thus, the value of managerial flexibility to alter the path of an investment, to spawn a new investment, or to pursue a sequential investment in stages cannot be fully accounted for in traditional DCF valuation models, and, as a result, the use of such static valuation models is called into question. Given the importance of valuation in strategic planning decisions (Robins, 1992; Varaiya et al., 1987), these arguments suggest that such decisions based solely upon standard DCF models may be based upon incorrect assessments of value.

In recent years, the real option approach (ROA) to capital budgeting, and its associated real option valuation models, has gained acceptance in the strategy literature (e.g. Bowman & Hurry, 1993; Folta & Miller, 2002; Kogut & Kulatilaka, 1994; McGrath, 1997; Reuer & Leiblein, 2000). A real option gives a firm the right, but not the obligation, to take a certain action, sometime in the future, at some cost. These models allow for contingent decision-making, i.e., decisions can be made later based on the actual unfolding of events, and do so by being able to value asymmetric payoffs, which lie at the heart of option pricing. Thus, an option-based valuation can value managerial flexibility by accounting for non-linear and dynamic decision-making, and is a reasonable representation of the logic of managerial decision-making. In practice, capital investments are determined by managerial discretion, where the firm's available options to (dis)invest in real assets are evaluated on an ongoing basis – then exercised, deferred, or allowed to expire (Myers, 1977).

Myers (1977) suggests that the market value of a firm is composed of the value attributable to its assets in place (V_{aip}) and the value attributed to its growth options (V_{go}): $V_{\text{firm}} = V_{\text{aip}} + V_{\text{go}}$. Kester (1984) refers to V_{go} as the value attributable to growth options since the future growth opportunities are similar to call options. Furthermore, he suggested that the DCF model only captures the value of the assets in place (V_{aip}), and not the value of growth options (V_{go}) – *the value of "strategic factors."* Specifically then, growth options give the firm the right, but not the obligation, to make a follow-on investment in the future, again, at some cost. For example, consider a European firm thinking about entering the consumer packaged goods industry in India. By establishing a distribution system and a sales force for a particular packaged good, the firm has acquired the right to distribute and sell additional consumer packaged goods in the future. As a further example, consider Intel. By investing in the development of the first microprocessor, Intel acquired the right to invest in the next generation of microprocessors.

In fact, there is often a chain or series of growth options embodied in an initial project. For the hypothetical consumer packaged goods firm just discussed, having established a single product, a second, third, and so forth can be marketed. At some point this could lead to the establishment of a pilot plant, followed by a full-scale plant. This plant could then lead to expansion to neighboring countries in the same pattern followed in India. In the case of Intel, investment in a second-generation microprocessor led to a third generation, then a forth generation, and so on. These compound growth options turned out to be extremely profitable for Intel. This logic obviously applies to other firms as well.

The growth option value that Kester (1984) determined for each firm actually represents the present value of the total chain of the firm's growth options. According to Kester (1984), the value of growth options represented 69% of market value for firm in the computer industry, 68% for electronics firms, 58% for chemicals firms, 44% for tire/rubber firms, and 29% for food processing firms. Thus, the portion of a firm's market value attributable to growth options appears to vary by industry, although no definitive statement is possible due to the nature of the limited sample.

Given that most firms continue to rely heavily on DCF valuation models (Graham & Harvey, 2001), the ability of a firm to effectively and strategically allocate its resources, and, thus, to survive in the competitive marketplace, is dependant on the firm understanding the limitations of the DCF valuation framework. Consequently, drawing on the general approach of Kester (1984), we use his original research design, and then we extend his conceptual approach to a more sophisticated DCF model to further explore the predictive ability of the traditional DCF valuation framework.

RESEARCH METHODS AND RESULTS

This research employs a three-phase design. The first phase involves the replication of Kester's (1984) original model, now using a large cross-sectional sample of firms. While Kester's (1984) arguments have enormous intuitive appeal, the empirical support provided by his study is limited with only 15 firms in the sample. The second phase also employs Kester's (1984) model, but with cash flows used as inputs to the model instead of earnings. Cash flow is a more appropriate measure of value according to finance theory. The third phase extends Kester's (1984) conceptual approach to a multi-period DCF model, which is a more appropriate model for valuing a firm's equity, and is similar to the valuation models commonly taught in business schools, as well as those used in practice. It is this third phase that represents the "perfect foresight" approach, comparing a firm's intrinsic value based upon actual cash flows with its actual market value.

Data and Sample

The sampling period for this study extends from 1989 to 1998. The initial sample consists of the firms that comprised the S&P 500 as of January 1, 1989 combined with the S&P 500 membership list as of December 31, 1998, i.e., firms that existed in the S&P 500 at the beginning (1989) and/or end (1998) of the sampling period. While most firms remained on the S&P 500 list for the full 10-year sampling period, the membership list of the S&P 500 does change over time. As a result, the combined list of the S&P 500 at these two points in time consists of 675 large public companies from a cross-section of industries. However, calculations in the DCF models used in this research require data for each firm from 1986 to 1999. Due to missing data the sample is reduced to 448 firms, although for particular analyses this number is reduced further.

Each DCF valuation performed uses actual equity cash flows rather than ex ante forecasts or estimates. The values yielded by the DCF models represent the intrinsic values of the firms as of January 1, 1989. Since we are using actual cash flows, it is as if the analyst on January 1, 1989 has a completely accurate forecast. For example, for the multi-period DCF model, we make the assumption that the analyst has exact forecasts on January 1, 1989 of the firm's equity cash flows for 1989–1998. The individual data items necessary to determine the actual equity cash flows are obtained from COMPUSTAT.

To assess the predictive ability of each DCF model, we compare a firm's intrinsic value on January 1, 1989 to its January 1, 1989 market value. Specifically, we use the log of the ratio of the intrinsic DCF value to market value, similar to Kaplan and Ruback (1995). This log ratio represents a measure of the valuation error of the DCF model. If the intrinsic value equals market value, the ratio will be 1, and the log ratio will be zero. If the intrinsic value is less (greater) than market value, the ratio will be less (greater) than 1 and the log ratio will be negative (positive). Kaplan and Ruback (1995) suggest the use of the log ratio because it "…is symmetric with respect to overestimates and underestimates" (p. 1070). We perform two-tailed *t*-tests to determine whether the valuation errors are significantly greater/less than zero. It also should be noted that, similar to Kester (1984), we assume throughout this research that the market value of a firm is the "true" value of the firm.

Phase One: Replication of Kester (1984)

Using firm earnings for a single year (1983) and a range of discount rates (15, 20, and 25%), Kester (1984) calculates each firm's value using a simple perpetuity model.

$$\text{Firm intrinsic value} = \frac{\text{Firm annual (1983) earnings}}{\text{Discount rate}}$$

For this phase of our research, we replicate Kester's (1984) analysis, using the new sample of 448 firms. We use 1989 earnings available to common shareholders and follow Kester's (1984) exact design – annual earnings capitalized at 15, 20, and 25% – to determine a range of intrinsic values for each firm. This tests whether or not Kester's (1984) findings can be replicated using a more recent and larger sample.

Phase Two: Replication of Kester (1984) using Cash Flows

For the second phase of this study, we use 1989 cash flow to equity, not earnings, and, again, follow Kester's (1984) design – annual equity cash flow capitalized at 15, 20, and 25% – to determine a second range of intrinsic values for each firm. We do this second analysis to determine if Kester's (1984) findings can be supported using a more recent and larger sample *and* a theoretically superior source of value – cash flow. According to finance theory, the value, or worth, of an asset is the present value of the future cash flows – not earnings – the asset is expected to generate. The general formula for determining a firm's annual cash flow to equity is as follows[3]:

$$\text{Year } t \text{ cash flow to equity} = \text{Year } t \text{ net change in cash} + \text{Year } t \text{ cash common stock dividends paid}$$

The net change in cash incorporates payments to creditors, federal and state governments, and other stakeholders, and, thus, represents the cash available to the common shareholders. However, cash common stock dividends paid, which appears as a reduction to the net change in cash, also represents payments to the common shareholders, and so needs to be added back. The net change in cash and the cash common stock dividends paid were both obtained from each firm's year t statement of cash flows for this particular analysis, year t is 1989.

There seems to be no reason to believe there has been a fundamental change in how market participants conceptually view and ascribe value to corporate growth opportunities. Kester's (1984) findings would suggest, then, that we should expect both perpetuity models to undervalue, to various degrees, a firm's market value, and that we should see negative log ratio valuation errors.

Results of Phases One and Two: Replication of Kester (1984) with Earnings and Cash Flow

The mean 1989 earnings for firms in our sample is 247.04 with a standard deviation of 493.31. The mean 1989 cash flow to equity is 129.01, with a

Table 1. Results of Phases One and Two – Tests to Replicate Kester's (1984) Model.

Mean valuation errors (log of intrinsic value/market value)

	Mean Valuation Error Discount Rate = 15%	Mean Valuation Error Discount Rate = 20%	Mean Valuation Error Discount Rate = 25%
Phase one: earnings ($N = 448$)	−56.49% $t = -18.052$ $p < 0.01$	−85.25% $t = -27.246$ $p < 0.01$	−107.57% $t = -34.377$ $p < 0.01$
Phase two: cash flow to equity ($N = 336$)	−138.48% $t = -21.008$ $p < 0.01$	−167.24% $t = -25.372$ $p < 0.01$	−189.56% $t = -28.758$ $p < 0.01$

Growth option value (1 – exp(mean valuation error))

	Growth Option Value as % of Market Value Discount Rate = 15%	Growth Option Value as % of Market Value Discount Rate = 20%	Growth Option Value as % of Market Value Discount Rate = 25%
Phase one: earnings ($N = 448$)	43.16%	57.36%	65.89%
Phase two: cash flow to equity ($N = 336$)	74.96%	81.22%	84.98%

standard deviation of 421.485. Table 1 presents the results of the two replications (earnings and cash flow to equity) of Kester's (1984) research.

Results indicate that, on average, a perpetuity model noticeably undervalues a firm's market value, assuming the correct assessment of firm value is its market value, and regardless of the source of value – earnings or cash flow to equity. The log ratio valuation errors range from −56.49% to −107.57% for the earnings model and from −138.48% to −189.56% for the cash flow to equity model. All results are significant at the 1% level. On the surface, our initial tests appear to support Kester's (1984) findings; however, a more detailed reconciliation suggests that Kester (1984) may have underestimated the amount of firm value attributable to growth options.

Kester (1984) subtracted the intrinsic value from the market value to determine the percent of market value attributed to growth options. Kester (1984) found this percentage to range for the 15 individual firms in his sample from 4% to 88%, with an average of 41.9% (15% discount rate) and 65.13% (25% discount rate). When the valuation errors in Table 1 are converted to a percentage of market value, our analysis suggests that growth options represent, on average, 43.2% (15% discount rate), 57.4% (20% discount rate), and 65.9% (25% discount rate) of market value when earnings are used. Thus, our earnings model results of phase one are of similar magnitudes as those of Kester's (1984). However, when cash flows are used instead of earnings, growth options represent, on average, 74.9% (15% discount rate), 81.2% (20% discount rate), and 84.9% (25% discount rate) of market value. Since cash flows represent a more appropriate measure of firm value, this suggests the portions of firm market values attributable to the value of growth options may actually be substantially larger than those observed by Kester (1984). It is worth noting here that our analysis is based on 1989 cash flows, when economic conditions varied substantially from the early 1980s when Kester's analysis was conducted. We will return to this observation later.

Phase Three: Extension of Kester (1984)

The perpetuity models used in the first two phases of this research are very simple models, and do not necessarily represent those used in practice or taught in business schools. In many ways they represent the calibration of our results and sample back to Kester's original work. We next extend Kester's (1984) work by testing the predictive ability of a more detailed – 10-year – DCF model. The 10-year period provides an opportunity to capture the variation in long-term performance of firms and also changing macroeconomic and industry conditions. We continue to use "perfect foresight" data in the form of actual annual equity cash flows, equity rates of returns, or stock price movements as valuation model inputs. But now we assume a 10-year investment horizon, and determine the intrinsic value of the firm as the sum of (1) the 1989 present values of the firm's annual (1989–1998) cash flows to equity and (2) the 1989 present value of the firm's ongoing, more commonly called residual, value (1999 and on). Thus, the January 1, 1989 intrinsic value of the firm is determined as follows:

$$\begin{aligned}&\text{Jan. 1, 1989 Intrinsic Value of the Firm} =\\&\quad\text{Jan. 1, 1989 Present Value of the 1989 to 1998}\\&\quad\text{Annual Cash Flows to Equity}\\&\quad+\text{Jan. 1, 1989 Present Value of the Dec. 31, 1998 Residual Value}\end{aligned}$$

Although the weighted average cost of capital (WACC) is often used in a DCF model, we are analyzing cash flows to equity, and so use an equity rate of return. We determine the equity rate of return in two ways: actual rates of return to equity and using the Capital Asset Pricing Model (CAPM).

Since we are using "perfect foresight," i.e., ex post data, we first use actual firm performance to determine the equity rates of return. The Year t equity rate of return is determined as follows:

$$\text{Year } t \text{ equity return} = \frac{\text{Stock price @ end of year } t + \text{common dividends paid in year } t}{\text{Stock price @ end of year } t-1} - 1$$

We calculate the actual equity rate of return for each firm for each year from 1988 to 1999, and, in order to avoid skewing a given valuation due to an unusually high or low return in any single year, we use 3-year moving averages of actual equity returns as our discount rates. To calculate the January 1, 1989 present value of the 10 (1989–1998) annual cash flows to equity, each annual cash flow is discounted one year at a time using the 3-year moving average equity rates of return actually experienced during the sampling period. The January 1, 1989 present values of the 10 cash flows are then added together.

In order to provide a comparative example of varying assumptions, we also calculate a cost of equity based on the CAPM model, which is an expectations model, i.e., an ex ante framework. Traditional DCF models typically use equity rates of return determined by using the CAPM for discounting cash flows to equity holders. A CAPM cost of equity is calculated as the sum of (1) the risk-free rate of return and (2) the risk premium (i.e., the market risk premium multiplied by the firm's beta). This cost of equity is calculated for each firm for each year in the sampling period. We do not use a 3-year moving average as CAPM determined rates of return are not as volatile and cannot be negative. The risk-free rate used for each year is the yield to maturity on long-term government bonds, obtained from Ibbotson Associates' 2006 Yearbook. We use Kaplan and Ruback's (1995) historical market risk premium of 7.42% as the market risk premium for each year in our model. Following Miller and Bromiley (1990), we calculated each firm's beta for each year by regressing the firm's daily common stock returns against the daily returns to the S&P 500 index. We again calculate the January 1, 1989 present value of the 1989–1998 annual cash flows to equity by first discounting each annual cash flow one year at a time, now using the CAPM determined annual rates of return, and then summing the present values of the 10 cash flows.

For our purposes here, the firm's residual value represents the value of the firm for 1999 and beyond, as of the end of 1998. Consistent with finance theory and practice, we model the residual value as a perpetuity. We first assume a 4% growth rate for the cash flows to equity that occur after 1999, which is the rate Kaplan and Ruback (1995) used.

$$\text{Firm residual value Dec. 31, 1998 } (g = 4\%) = \frac{\text{1999 equity cash flow}}{[3 - \text{year moving average discount rate for 1998}] - 0.04}$$

or

$$\text{Firm residual value Dec. 31, 1998 } (g = 4\%) = \frac{\text{1999 equity cash flow}}{[\text{CAPM discount rate for 1998}] - 0.04}$$

We also calculate the firm's residual value using 0% growth in the firm's cash flows to equity. However, for the 0% growth model, in order to reflect no growth in the cash flows we must adjust the 1999 equity cash flows so that depreciation equals capital expenditures and acquisitions and the change in net working capital is zero.

Negative residual values occur when the 1999 cash flow to equity is negative. Since 1999 occurs during an economic boom, a negative 1999 cash flow to equity could be due to a high level of firm capital expenditures that year. Alternatively, a negative residual value might suggest that the firm is no longer a viable entity, and, therefore, should be dropped from the sample, similar to firms that became non-viable entities and data was no longer available. Whatever the reason for the negative 1999 equity cash flow, modeling negative equity cash flows into perpetuity is not reasonable; a firm having a negative residual value is not representative of an ongoing firm. If a firm's 1999 equity cash flow is negative but the 1998 equity cash flow is positive, the 1998 equity cash flow is compounded forward one period using a 4% growth rate. If both the 1999 and the 1998 equity cash flows are negative, the firm was excluded from the sample for the 10-year, multi-period DCF model.

$$\text{Firm residual value Dec. 31, 1998 } (g = 4\%) = \frac{\text{1998 equity cash flow} \times 1.04}{[3 - \text{year moving average discount rate for 1998}] - 0.04}$$

or

$$\text{Firm residual value Dec. 31, 1998 } (g = 4\%) = \frac{\text{1998 equity cash flow} \times 1.04}{[\text{CAPM discount rate for 1998}] - 0.04}$$

The January 1, 1989 present value of the residual value is determined by discounting its 1998 value, year by year, using either the actual 3-year moving average or the annual CAPM-based equity rates of return, exactly as was done with the annual cash flows to equity.

The final step, again, is to assess the predictive validity of this 10-year, multi-period DCF model by comparing each firm's resulting intrinsic value with its market value as of January 1, 1989 using the valuation error measure from Kaplan and Ruback (1995), as previously described. Although using actual cash flows for ten years captures the value of the firm's exercised growth options, the firm may still have unexercised growth options or acquired additional growth options. In fact, it is a question of substantial interest to see what option value lies beyond our 10-year ''perfect foresight'' horizon. We continue to see no reason to expect the DCF intrinsic values to be, on average, equal to or greater than the firms' market values. Thus, we continue to expect to see negative log ratio valuation errors.

Results of Phase Three: Extension of Kester (1984)

Table 2 shows the valuation errors of the 10-year, multi-period DCF model.

As Table 2 shows, Model 1 (actual returns to equity and 4% growth in the residual value cash flows) appears, on average, to fairly approximate or even slightly, though not significantly (11.02%, $p = 0.07$), *overvalue* a firm's market value. In terms of growth option value, growth options

Table 2. Results of Phase Three – Tests of Predictive Ability of the 10-Year, Multi-Period DCF Model.

Model 1: Discount Rate = Actual Return on Equity; 4% Growth Rate in Residual Value Calculation ($N = 448$)	Model 2: Discount Rate = Actual Return on Equity; 0% Growth Rate in Residual Value Calculation ($N = 448$)	Model 3: Discount Rate = CAPM Approach; 4% Growth Rate in Residual Value Calculation ($N = 268$)	Model 4: Discount Rate = CAPM Approach; 0% Growth Rate in Residual Value Calculation ($N = 268$)
Mean Valuation Errors (log of intrinsic value/market value)			
11.02%	36.80%	−72.24%	−103.11%
$t = 1.807$	$t = 5.199$	$t = -10.47$	$t = -15.44$
$p = 0.07$	$p < 0.01$	$p < 0.001$	$p < 0.001$
Growth Option Value (1 – exp(mean valuation error))			
−11.65%	−44.48%	51.44%	64.34%

represent −11.65% of the firm's value, on average. Model 2 (actual returns to equity and 0% growth in the residual value cash flows) significantly *overvalues* the firm (36.80%, $p<0.01$), with growth options representing −44.48% of the firm's value, suggesting that the value of the assets in place approximate or exceed the market value of the firms in the sample, on average. Both of these results are somewhat surprising, and contradict those of Kester (1984) as well as those of our two replications of Kester's (1984).

We see noticeably different results with the CAPM determined rates. Model 3 (CAPM determined rates and 4% growth in the residual value cash flows) significantly *undervalues* the firm (−72.24%, $p<0.001$), and growth options represent over 51% of the firm's value on average. Model 4 (CAPM determined rates and 0% growth in the residual value cash flows) again significantly *undervalues* the firm to the tune of −103.11% ($p<0.001$), with growth options representing over 64% of firm value. These results of the CAPM model are very much in line with those of Kester (1984) and as reported in Table 1.

The results in Table 2 highlight that different discount rate assumptions can considerably alter the results of the model which, in turn, may impact the decision of the manager. The change from overvaluation using actual returns to equity to undervaluation when using CAPM suggests that the discount rates in the CAPM model are somewhat larger than the actual returns model, resulting in lower intrinsic values for the CAPM models. The average discount rate across all firms and years for the actual returns model is 5.69%. The average discount rate for the CAPM model is 13.65%. A t-test reveals that the difference between these two means is a significant one, with a t-statistic of 11.654 ($p<0.001$).

The difference between the actual returns to equity and the CAPM determined rates drive the noticeably different mean valuation errors and associated growth option values. The lower bound on a CAPM-based discount rate is the risk-free rate of return, which ranged over the 1989–1998 period from a low of 5.42% in 1998 to a high of 8.44% in 1990. The discount rates based on actual returns to equity do not have such a lower limit. Their theoretical lower limit is −100%; however, for this study we eliminated observations with for which the 3-year average discount rate is negative. Thus, the real lower limit for actual rates of return is 0%. Why actual rates of return were so much lower than our CAPM determined expected rates during this period is beyond the scope of this research. But it appears that during 1989–1999 actual rates were far lower than expected rates, and the resulting valuations surely underscore the importance of modeling assumptions and estimation methods. The higher CAPM (expected) rates are closer to Kester's high rates (15, 20, and 25%), which produce lower levels of the asset in place component and a higher growth option component of firm value.

One other point related to Table 2 deserves some attention. At first glance, the comparison of the valuation errors between 4% and 0% growth in the residual value cash flows models may appear counterintuitive since the valuation error for the 0% model exceeds that of the 4% model. A higher growth rate would normally be expected to lead to a greater residual cash flow and thus a greater intrinsic value. However, the result is consistent with valuations done in practice. In the 0% model, as explained above, the residual value cash flows are adjusted so that depreciation equals capital expenditures and acquisitions, and the change in net working capital is zero. During periods of high growth, this adjustment effectively increases the residual value cash flow amount substantially, producing a high DCF value. In the 4% growth model, since this adjustment is not made, the residual value cash flow is lower, and, while the 4% growth rate does increase the DCF value, the growth rate is not sufficient to account for the cash flow adjustments made in the 0% growth model.

Further Analysis

To further explore our results from phase three, we conduct additional analysis, focusing on macroeconomic conditions and industry effects. Each of these could be a factor that influences the value of the growth opportunities actually available to a firm or as perceived by market participants. During periods of economic growth, firms most likely have ample access to the capital necessary to pursue growth opportunities. In contrast, during periods of economic decline, firms may not have the capital or other necessary resources to pursue growth opportunities, thus limiting the perceived value of their growth options. Furthermore, as Kester's (1984) results indicate, the percentage of firm value attributable to the value of growth options varies by industry. This suggests an industry effect of growth options, which is supported by Tong and Reuer (2006).

Further Analysis: Macroeconomic Conditions

The 10-year sampling period used in this research, 1989–1998, experienced a wide range of economic conditions and represents a time that witnessed both sides of a business cycle. During approximately the first half of the sampling period, the late 1980s and early 1990s, the economy experienced an economic recession. The economy emerged from the recession around 1992 or 1993, and entered an economic boom that is still underway at the end of the sampling period, 1998. Thus, we partition the 10-year sampling period into two 5-year periods, 1989–1993 (economic recession) and 1994–1998 (economic boom). We then reassess the predictive ability of the multi-period DCF model for these two 5-year sub-periods. Table 3 presents the results of these tests.

During the first 5-year period (1998–1993: economic recession), Table 3a, the models using actual returns on equity (Models 1 and 2) reasonably

Table 3. Results of Further Analysis – Tests of Predictive Ability of the Multi-Period DCF Model Using 5-Year Sub-Periods.

(a) Recession period: 1989–1993

Model 1: Discount rate = actual return on equity; 4% growth rate in residual value calculation ($N = 187$)	Model 2: Discount rate = actual return on equity; 0% growth rate in residual value calculation ($N = 187$)	Model 3: Discount rate = CAPM approach; 4% growth rate in residual value calculation ($N = 167$)	Model 4: Discount rate = CAPM approach; 0% growth rate in residual value calculation ($N = 167$)
Mean valuation errors (log of intrinsic value/market value)			
−9.88%	10.39%	−83.60%	−107.95%
$t = -1.154$	$t = 1.336$	$t = -13.03$	$t = -17.26$
$p = 0.25$	$p = 0.18$	$p < 0.001$	$p < 0.001$
Growth option value (1 – exp(mean valuation error))			
9.41%	−10.95%	56.66%	66.02%

(b) Growth period: 1994–1998

Model 1: Discount rate = actual return on equity; 4% growth rate in residual value calculation ($N = 232$)	Model 2: Discount rate = actual return on equity; 0% growth rate in residual value calculation ($N = 232$)	Model 3: Discount rate = CAPM approach; 4% growth rate in residual value calculation ($N = 181$)	Model 4: Discount rate = CAPM approach; 0% growth rate in residual value calculation ($N = 181$)
Mean valuation errors (log of intrinsic value/market value)			
−45.46%	−13.41%	−134.99%	−171.45%
$t = -6.514$	$t = -1.779$	$t = -17.25$	$t = -24.73$
$p < 0.01$	$p < 0.08$	$p < 0.001$	$p < 0.001$
Growth option value (1 – exp(mean valuation error))			
36.53%	12.55%	74.07%	81.99%

estimate a firm's market value. The valuation errors range from −9.88% to 10.39%, and growth option value represents 9.41% and −10.95%, respectively. When using the CAPM-based discount rate (Models 3 and 4), the DCF models significantly undervalue the market value with valuation errors ranging from −83.60% to −107.95%. Growth option value represents approximately 56–66%, respectively. In the second 5-year period (1994–1998: economic boom) in Table 3b, the DCF models based on actual returns both undervalue a firm's market value, ranging from −13.41% to −45.45%, with growth option value representing between 12% and 36% of the market value, respectively. The CAPM-based models show a greater magnitude of undervaluation, with valuation errors ranging from −134.99% to −171.45%, and growth option values representing 74–82% of the firm's market value.

The overall results suggest that economic conditions have an effect on investor expectations and that these expectations can alter market values as well as resulting intrinsic values. All four models indicate that investors were somewhat less optimistic during the recessionary period, with substantially lower levels of growth option value present in the market value of the firm. However, in the economic boom of the late 1990s, investors' expectations seemed to have changed, resulting in higher levels of growth option value for all three models. The results in Table 3 again underscore the impact of varying assumptions on the valuation process, and also may reflect information asymmetries between insiders and outsiders related to valuation as noted by Zingales (2000).

Comparing Tables 2 and 3 shows that the percent of value attributed to growth options varies across models and time periods. For the full 10-year model in Table 2, the actual return model growth option values ranged from −11.65% to −44.48%, while the CAPM model growth option values ranged from 51.44% to 64.34%. In Table 3a, the GOV percentages for the recession period ranged from 9.41% to −10.95% for the actual returns model, and from 56.66% to 66.02% in the CAPM model. Finally, in Table 3b, the growth period, the GOV percentages for the actual returns model range from 36.53% to 12.55%, and from 74.07% to 81.99% for the CAPM model. We compared the correlations between the GOV percentages of the different models. Interestingly, we found that the correlations between GOV percentages were positive and significant (all above 0.200 with the majority above 0.900) within the same time period (10-year, first 5-year, or second 5-year) even across the different discount rates. However, the GOV percentages were not correlated across the three time periods. This further supports the notion that GOV is linked to assumptions in the model, which will be discussed further below.

Further Analysis: Industry Variation

Industries differ in terms of their structure, profit potential, life cycles, and growth trajectories. Hence, it is reasonable that the availability of growth opportunities might differ across industries. Kester's (1984) results did seem to suggest variation in growth option value by industry – electronic and computer firms, on average, had higher growth option values and food-processing firms, on average, had lower growth option values. Hence, we explore the variance in valuation errors and growth option values across industries in our sample. We focus on Models 1 and 3 to compare industry variation between the actual returns-based and CAPM-based models. To investigate the impact of industry we partitioned the data according to industry membership based on the single-digit SIC Codes, obtained from COMPUSTAT. One modification was made to the SIC Divisions: industries relating to technology were broken out separately. Categorizing the sample firms in this manner leads to 11 industry groups: (1) Conglomerates; (2) Construction; (3) Finance, Insurance and Real Estate; (4) Manufacturing; (5) Minerals; (6) Pharmaceuticals; (7) Retail Trade; (8) Services; (9) Technology; (10) Transport, Communication, and Utilities; and (11) Wholesale Trade. Six industry groups – Conglomerates, Construction, Minerals, Pharmaceuticals, Services, Wholesale Trade – consist of less than 15 firms each in our sample for both the actual returns-based and CAPM-based models, and are considered too small for any meaningful statistical analysis. Thus, we focus on the remaining five industry groups – Finance, Insurance and Real Estate; Manufacturing; Retail Trade; Technology; Transport, Communication, and Utilities; Wholesale Trade. Table 4 below presents the analysis of the predictive ability of the full 10-year, multi-period DCF model for these five industry groups.

As Table 4 shows, for Model 1, the actual returns-based model, the DCF model yields intrinsic values that reasonably approximate market value for firms in three of the five industry groupings – Manufacturing, Technology, and Transport, Communication, and Utilities. The model significantly overvalues (99.9%, $p<0.01$) firm value for the Finance, Insurance and Real Estate industry group, but it significantly undervalues (−33.4%, $p = 0.01$) firm value for the Retail Trade industry group. These findings appear to support Kester's (1984) implication that industries vary in terms of the level of growth options available to firms, even for the industries in Table 4 whose mean valuation errors are not significantly different from zero. However, these results are somewhat surprising, particularly with respect to the Technology industry group, where one would expect firms to have considerable growth opportunities available to them and the market to perceive substantial growth option value. In terms of growth option value as a

Table 4. Results of Further Analysis – Tests of Predictive Ability of the 10-Year, Multi-Period DCF Model.

	Model 1: Discount Rate = Actual Return on Equity; 4% Growth Rate in Residual Value Calculation	Model 3: Discount Rate = CAPM Approach; 4% Growth Rate in Residual Value Calculation
Mean valuation errors (log of intrinsic value/market value)		
Finance, insurance and real estate	99.9%	−95.3%
	$t = 5.24$	$t = -4.03$
	$p < 0.01$	$p = 0.002$
	$N = 31$	$N = 12$
Manufacturing	−7.4%	−79.1%
	$t = -0.85$	$t = -13.26$
	$p = 0.39$	$p < 0.001$
	$N = 86$	$N = 61$
Retail trade	−33.4%	−105.8%
	$t = -2.76$	$t = -5.62$
	$p = 0.01$	$p < 0.001$
	$N = 24$	$N = 21$
Technology	−13.9%	−199.2%
	$t = -0.64$	$t = -3.74$
	$p = 0.53$	$p = 0.02$
	$N = 17$	$N = 5$
Transport, communication, and utilities	17.1%	−20.7%
	$t = 1.30$	$t = -1.27$
	$p = 0.20$	$p = 0.22$
	$N = 40$	$N = 16$
Growth option value (1 – exp(mean valuation error))		
Finance, insurance and real estate	−171.56%	61.44%
	$N = 31$	$N = 12$
Manufacturing	7.13%	54.66%
	$N = 86$	$N = 61$
Retail trade	28.39%	65.28%
	$N = 24$	$N = 21$
Technology	12.98%	86.36%
	$N = 17$	$N = 5$
Transport, communication, and utilities	−18.65%	18.73%
	$N = 40$	$N = 16$

percentage of market value, we also find a range across industries. At the low end of the spectrum, the value of assets in place represents the entire market value for Finance, Insurance and Real Estate firms and Transport, Communication, and Utility firms. For manufacturing firms, growth options represent roughly 7% of firm value on average. Growth option value represents approximately 28% of firm value for Retail Trade firms. Finally, and most surprising, growth options only represent roughly 13% of firm value for Technology firms. The surprising results relating to Technology firms may be due to the nature of our calculation of intrinsic value. Since the intrinsic value includes the value of cash flows during the sampling period, it is likely that a portion of these cash flows include growth options that have been exercised. This may be particularly true in an industry such as Technology because of its fast cycle nature.

For Model 3, the CAPM-based model, the DCF model significantly undervalues the firm's market value for four of the five industries – only Transport, Communication, and Utilities are not significantly undervalued, although the sign of the valuation error is negative. This consistent undervaluation is to be expected given the results in Table 1 above. Given the undervaluation, the value attributable to growth option value represents between 18.73% and 86.36% of the market value. The largest percentage of growth option value is the Technology industry. The results of the CAPM-based model correspond to the findings of Kester's (1984) original study.

While the findings in Table 4 may differ between the actual returns-based model and the CAPM-based model, both models indicate that valuation errors vary across industries. The percentage of market value attributable to growth options also varies across industries. Although the magnitudes may differ from Kester, this latter conclusion appears to support Kester's (1984) earlier contentions. With the findings and supplementary analyses in mind, we now turn to a general discussion of implications of our findings.

DISCUSSION

The research reported in this paper was motivated by the work of Kester (1984), Myers (1977), and Bettis (1983). Valuation is a crucial link between strategic management and finance. The valuation process and the associated outcomes can have dramatic implications for strategic decisions. The overall purpose of this paper was to examine and extend Kester's (1984) findings relating to growth option value with a large statistically useful sample and alternative modeling approaches.

In terms of our direct replication of Kester (1984), our resulting estimates of growth option values seem to roughly correspond to those in the Kester (1984) sample. When the more theoretically correct cash flow to equity is substituted for earnings, the valuation errors are again large and negative, and estimated growth option values are substantially larger than Kester (1984) originally suggested from an earnings model, ranging from 75% to 85% of the market value of a firm. On the surface this would seem to suggest that Kester (1984) may have underestimated firm growth option value. However, it can be conjectured that the relatively difficult economic situation (high inflation and high interest rates) present in 1983 may have caused investors to be less sanguine about the future prospects for growth than they were in 1989.

The results for the more practical DCF model, the 10-year model, offer a different perspective, and indicate a potential conflict. When using actual returns to equity as a discount rate in the spirit of perfect foresight, the DCF model overvalues market value, either marginally or substantially depending upon the growth rate assumption in the residual value. The value attributable to growth opportunities ranges from almost −12% to over −44%. However, when using a CAPM-based cost of equity, similar to practice, the DCF model undervalues market value considerably, with growth option value accounting for approximately 51–64% of the firm's value. Thus, the former actual returns model contradicts Kester's (1984) findings, while the latter CAPM model supports Kester's (1984) findings.

To help understand the result for the full 10-year sampling period, it is useful to consider exactly what the10-year perfect information DCF valuations represent. They capture not only the value of cash flows from the assets in place as of the beginning of 1989, but also the value of growth of assets in place, the cash flows from growth options that were exercised, or allowed to expire, by the firms during the 10-year period, and the cash flows from new growth options investments. It is difficult to meaningfully separate these components using archival data, thus our estimates of growth option value may be slightly understated since growth options may have been exercised during the 10-year period and thus are included in the DCF value. In addition, the residual value captures a simple estimate of the ongoing value of the firm after the 10-year period. Since a number of firms were deleted due to negative residual cash flows at the end of the period, i.e., deleting negative residual values, there is the possibility that the growth option values may be understated. By deleting these firms we may have inflated residual values, on average, thereby overvaluing assets in place in our model, which results in lower growth option values, on average. While it is not possible to measure the impact of these effects, it is worth noting their existence.

The findings have several important implications for strategic decision-making and the role of valuation. Our findings clearly highlight the critical influence that assumptions and expectations have on the valuation process.

The differences between the actual return models versus the CAPM models demonstrate the obvious impact of differing discount rate assumptions. If managers and investors are using different rates, they may come to different conclusions as to the value of an investment, or the value of the firm. Such a situation can obviously force a reexamination of investments and/or strategy based on investor pressures expressed through the market valuations. This result may also rationally occur due to information asymmetries that exist between managers and investors, particularly related to hidden organizational assets (Zingales, 2000).

In addition, the findings of the analysis in Table 3 related to differing macroeconomic conditions provides further evidence of the critical role of both assumptions and expectations. The market clearly displays differing expectations with regards to future growth opportunities under different economic conditions. During tough economic times the findings imply that the market perceives fewer growth opportunities for firms. Investors appear to be pessimistic or myopic during economic recessions, which is not conducive to seeing future growth. However, the market perceives, on average and during such boom times, substantial growth opportunities available to firms. Economically good times lead to an optimistic attitude, which, in turn, is conducive to seeing a future resplendent with opportunity. Understanding the expectations and time horizons of investors may be useful in strengthening the relationship between firm market performance and strategic planning. The exploration of investor time horizons, including the effects of strategy, growth options and industry characteristics on such horizons, represents potential avenues for future research.

Another interesting implication involves the comparison of "perfect foresight" intrinsic value to market value. We basically test whether the market value, which is based on the market's expectations of future cash flows, is equal to the calculated value of the actual cash flows. The findings indicate that market value and intrinsic value are not always equal to each other, sometimes not even close. This supports the arguments of Kester (1984) and Myers (1984) in terms of the difficulty assessing the firm's growth options. It also provides evidence of Zingales' (2000) valuation challenge facing firms and investors. This discrepancy between intrinsic value and market value again signifies the potential for making incorrect investment decisions, as noted above, where the DCF value may undervalue or overvalue an investment relative to the market. This information asymmetry may lead to possible governance concerns in terms of monitoring and incentive alignment mechanisms. The market may put additional safeguards in place to ensure that managers are making investment decisions based upon market expectations, impacting the firm's resource allocation strategies. Future research may be directed toward examining the effects of governance on resource allocation decisions, exploring the structural and strategic context surrounding managerial decision making (Bower, 1970).

Our findings related to the industry analysis indicate that industry characteristics appear to play a role in the level of growth options available to a firm (Tong & Reuer, 2006). From a valuation perspective, DCF models may be less appropriate in certain industries. A more detailed analysis of industries with larger sample sizes for each represents an opportunity for future research.

In sum, the results raise important questions concerning the use of DCF models in the valuation practices of firms and the connection to the creation of shareholder value. The nature of the DCF model, along with the extent of recognition and incorporation of influential factors from the investment context, may lead to different valuations, leading to different investment choices and hence different strategies. Given that a firm's strategy is a result of iterations of resource allocation decisions (Noda & Bower, 1996), the impact of different assumptions and models may have a strong influence on a firm's strategic direction by affecting strategic investment decision-making. If managers and executives are to better tie investment in strategies and projects to the creation of shareholder value, these issues will have to be much better understood. (This is an obvious direction for future research.) Furthermore, growth option value (or, alternatively, DCF valuation error) is dependent on a number of different variables. It is to this issue we now turn.

The overall pattern of the results suggests that the growth option value contained in the market value of a particular firm depends on three general factors that impact investor expectations: (1) the macroeconomic environment; (2) the industry in which the firm participates; and (3) firm specific factors. This corresponds to the year, industry and firm effects found by Tong and Reuer (2006) in their variance decomposition of growth option value. A good deal of strategy literature and practice is directed toward the creation of growth options on the individual firm level. In fact, it could be argued, that the concept of core competence is, at base, a theory of growth option creation at the firm level. Obviously, all three of these factors change over time thereby altering the percentage of firm market value represented by growth option value. It should also be noted that the three factors probably interact in various complex ways. For example, the macro economy impacts different industries in different ways. Untangling the impact of various factors, and their interactions over time, represents a difficult but important issue for future research.

NOTES

1. Kester (1984) used the market value of each firm's equity, obtained from the August 12, 1983 Value Line Investment Survey, to represent the value of the firm's assets in place plus the value of the firm's growth options. We also use the market value of each firm's equity as total value. However, from this point forward, we use the term "market value of the firm" (or "the firm's market value") to mean the market value of the firm's equity, and we determine this value by multiplying the firm's stock price at time t by the number of outstanding shares at time t.
2. "Intrinsic value" refers to the value of the firm calculated by determining the present value of the firm's future cash flows (or earnings following Kester).
3. We focused on Net Change in Cash plus Dividends to measure cash flows to equity. Alternative methods to compute cash flows to equity exist in the literature, but use of these alternatives led to a loss in a large number of firms due to missing data. Comparing our approach to others, such as Kaplan and Ruback (1995) indicates that from a conceptual standpoint our method reasonably reflects cash flows to equity when taking into account all factors affecting flows to equity holders.

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AN EMPIRICAL EXAMINATION OF MANAGEMENT OF REAL OPTIONS IN THE U.S. VENTURE CAPITAL INDUSTRY

Isin Guler

ABSTRACT

This study empirically examines how firms manage real options over time in the context of the U.S. venture capital industry. It tracks the venture-capital funding histories of U.S. portfolio companies founded during 1989–1993, and their outcomes, until 2004. An examination of sequential investments suggests asymmetries in the management of successful and unsuccessful companies. Signals of a company's progress, such as the number of its patents, are significant predictors of VC investment practices in the case of successful companies, but not in the case of unsuccessful companies. In contrast, VC firm characteristics, such as experience in the company's industry, IPO experience, and geographic proximity, appear to explain variance in investment policies for unsuccessful companies, but not successful ones. This suggests that signals of progress are relatively easier to interpret when real options perform well over time, and investors can perhaps apply them equally effectively. In contrast, signals of failure are more ambiguous and complex; and firm-level differences are more pronounced in the management of unsuccessful options.

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INTRODUCTION

Real options allow firms to deal with uncertainty surrounding investments (e.g., Bowman & Hurry, 1993; Dixit & Pindyck, 1994; Trigeorgis, 1996). Prior research reports that firms use real options logic in managing portfolios of uncertain investment opportunities, such as R&D investments (Kumaraswamy, 1996; McGrath & Nerkar, 2004), business development options (Folta & Miller, 2002; Kogut & Kulatilaka, 1994), and venture capital or corporate venture portfolios (Gompers, 1995; Hurry, Miller, & Bowman, 1992). While most research on real options has focused on the adoption of real options logic and valuation of the options, issues related to the management of these investments over time have only recently started to capture attention (Adner & Levinthal, 2004; Coff & Laverty, 2001). However, management of real options is key to performance, since realization of the value of these options requires successful implementation over time. This includes a set of activities following the initial selection of investments, such as collecting new information, evaluating expected payoffs according to new information, and subsequently deciding to continue or abandon investments. A thorough understanding of real options in action, therefore, requires careful attention to the implementation of real options logic.

This study empirically examines how firms manage real options over time in the context of the U.S. venture capital (VC) industry. Venture capital investments provide an attractive setting for a study of real options. Each investment decision involves *expending resources* with a significant *opportunity cost* under conditions of *uncertainty* and *irreversibility* (Dixit & Pindyck, 1994).

Venture capital firms use real options logic in their investments on a regular basis. They typically invest in portfolio companies in multiple financing rounds, which provide them with options to continue or abandon investments over time. These investments are designed to help venture capital investors deal with uncertainty underlying the value of their investments. The ability to reap the most benefit from such investments depends on effective management of the options over time. Venture capitalists must identify the options that still offer positive value and continue investing in them, while abandoning options that are no longer valuable. I argue that both are important in managing portfolios of options, yet they may require different skills.

The study tracks the venture-capital funding histories of U.S. portfolio companies founded during the 1989–1993 period. It focuses on sequential investments in the portfolio companies, until 2004, and their outcomes.

I identify companies that achieved a successful exit as of 2004 and the ones that did not. I then retrospectively examine VCs' sequential investment practices and explore investment patterns in these two subsamples. The results suggest that asymmetries exist in the management of successful and unsuccessful investments. While signals of a company's progress, such as the number of its patents, are significant predictors of VC investment practices in the case of successful companies, they are not significant predictors of VC investments in unsuccessful companies. In contrast, VC firm characteristics, such as experience in the company's industry, initial public offering (IPO) experience, and geographic proximity, appear to explain the variance in investment policies for unsuccessful companies, but not successful ones. This suggests that signals of progress may perhaps be relatively easier to interpret in the case of successful companies, and venture capital firms can apply them equally as effectively. In contrast, signals of failure are more ambiguous and complex and firm-level differences are more pronounced in the management of unsuccessful companies. More generally, this finding lends support to the argument that firms face challenges in the implementation of real options logic over time, especially when the investment is not performing well (Adner & Levinthal, 2004; Coff & Laverty, 2001). It highlights managerial challenges in implementing real options over time. It also demonstrates asymmetries in the management of options that perform well, and those that perform poorly. While management of "successful" options requires careful attention to objective signals of success, management of "unsuccessful" options requires subjective judgment about whether to continue or terminate investments. In consequence, firm-level differences in the management of unsuccessful options appear more pronounced, and may potentially affect firm performance.

SEQUENTIAL INVESTMENTS AND REAL OPTIONS

An option is the right, but not the obligation, to take an action in the future (Amram & Kulatilaka, 1999). By buying an option to buy or sell an asset at a predetermined exercise price, investors can protect themselves from the adverse affects of future price fluctuations. Since there is no obligation to exercise the option if its value falls below its exercise price, the downside of investment is limited to the purchase price of the option. The upside is unlimited, based on the value of the asset at the exercise date. Since the upside potential of options increases under uncertainty, options become more valuable when the level of uncertainty is high.

By analogy, real options provide firms with opportunities to make (or abandon) subsequent commitments to a project at a future date, without an obligation to do so. Real options can be growth options, which allow firms to make subsequent investments in a project that is going well, or to leverage the project as a platform for new investment opportunities (Amram & Kulatilaka, 1999; Kim & Kogut, 1996; Kogut & Kulatilaka, 1994). They can also be exit options, which allow the firm to abandon investment if the project is not going well. Firms use real options logic in many decisions under uncertainty. For instance, firms leverage minority stakes in partner organizations as options to bring the partner in-house (Folta & Miller, 2002). Investments in R&D and patenting have been characterized as options to pursue further investment in a technological area (McGrath, 1997; McGrath & Nerkar, 2004). Foreign direct investments in a country may serve as options to expand to other countries (Kogut & Kulatilaka, 1994).

While some real options decisions may be one-shot (e.g., acquisition of a venture after a minority transaction), many occur sequentially, in multiple stages (e.g., pharmaceutical drug development that involves several phases of development and testing, or venture capital investments that involve several rounds of financing). In such cases, investment at each stage gives the firm the opportunity to participate in subsequent stages. These investments are akin to compound options, where the value of the option at any stage includes the value of the subsequent options as well as the immediate one.

Sequential investments involve an iterative process of information acquisition and incremental commitment over a substantial period of time. Each subsequent investment provides the investor with more information about the likelihood of success. However, each investment also has an opportunity cost because resources may be invested in exploring new alternatives. Therefore, the investor decides between investing to gain more information about the ultimate payoff of existing projects and investing in new alternatives.

Uncertainty about each option's payoff structure may have both endogenous and exogenous components from the investor's point of view (Folta, 1998). The probability of success is endogenous to the extent that the outcome depends on the actions of the investor. To further explore the example of pharmaceutical drug development, the likelihood of discovering a profitable drug molecule is almost zero unless the right amount of capital and effort are devoted to research and subsequent phases of product development. This likelihood increases with appropriate investment in R&D. This component of the likelihood of success captures the growth of the project's value with proper management of resources.

At the same time, there is a stochastic component of success that is exogenous to the investor. This part of the distribution may be affected by the intrinsic value of the project, as well as other, unobserved factors that may affect the project performance, regardless of the investor's actions. No matter how much investment the pharmaceutical company allocates to research, some projects are intrinsically more likely to become successful than others. This component of the probability distribution captures the uncertainty in the project's value.

Sequential investments help uncover additional information about the underlying value of the particular project. The advantage of utilizing a sequential approach to investments is that it provides firms with more flexibility in their investment process, compared to a one-shot investment. Instead of committing a large amount of capital upfront, the firm can invest small amounts to learn about the underlying value of the project and decide whether to make subsequent investments based on information about the progress of the company. At each stage, the investor is to decide whether to invest further in discovering the underlying value of a particular project or to abandon the investment. The flexibility advantage can only be enjoyed if the firm abandons investments that are no longer "in the money", and utilizes its resources in other, more promising projects.

VENTURE CAPITAL INVESTMENTS AS REAL OPTIONS

Venture capital investments in portfolio companies comprise examples of real options logic (Amram & Kulatilaka, 1999; Gompers & Lerner, 2000; Hurry et al., 1992). This section briefly describes the venture capital investment process and then explains how real options thinking applies to venture capital investments.

VC firms[1] are typically organized as limited partnerships, where general partners raise capital from limited partners for specific funds and manage the funds over a fixed duration (typically 10 years). Limited partners include institutional investors and wealthy individuals. Among institutional investors, corporate and public pension funds comprise the largest investor group, followed by endowments and foundations, bank holding companies, insurance companies, investment banks, non-financial corporations, and foreign investors (Fenn, Liang, & Prowse, 1997). General partners manage funds by selecting and monitoring a portfolio of investments and liquidating investments ('exiting') to return the capital to limited partners. VC firms' performance is measured in terms of the returns to each fund. Returns on previous funds drive the general partners' ability to raise capital for new funds.

Venture capitalists select portfolio companies through a rigorous screening process. A typical VC firm invests in only 1% of the business proposals received (Fenn et al., 1997). VC firms often expect to remain involved in each portfolio company for 5–7 years (Fenn et al., 1997). During this period, they monitor the progress of the company, and provide resources and advice, to ensure that the company is moving toward a successful exit option. VC firms can exit portfolio companies through IPOs, acquisitions/mergers, or stock buybacks. Venture capitalists typically earn the highest rates of return when the portfolio company goes public (Gompers & Lerner, 2000). Therefore, successful exit options from the venture capitalists' perspective are public offerings, or acquisitions at favorable prices.

VC firms typically specialize in high-risk investment opportunities, such as start-up companies in unproven, high-technology industries. As a result, returns to VC investments are highly skewed, i.e., a small number of investments account for a large proportion of portfolio returns (Scherer, Harhoff, & Kukies, 2000). Only between 10 and 30% of VC investments result in an IPO (Fenn et al., 1997). The top 10% of VC investments between 1969 and 1988 accounted for 62% of the returns (Scherer et al., 2000). In this period, over 30% of VC investments resulted in a net loss (Sahlman, 1990).

It is this uncertainty over the likelihood of a successful exit that the VC firm attempts to uncover through sequential rounds of financing. Since a large proportion of portfolio companies provide little or no returns, estimation of the likelihood of success, and abandonment of unsuccessful investments, is key to overall portfolio performance. Each round of investment is an option to acquire more information about the developing prospects of the company. Additional investment helps reveal new information that gradually resolves the technological and demand uncertainty that the company faces. Venture capital firms typically manage this process by setting milestones for each portfolio company and then evaluating the progress of the company toward the milestones. If the company has met the milestones and is successfully moving toward a favorable outcome, the venture capital firm continues investment. If, on the other hand, the venture capitalist receives "bad news" about the opportunity, i.e., the company fails to show significant progress, the VC is to terminate investment in the company and explore other opportunities. Theoretical models of VC investment assume that firms revise their estimated probabilities of success through a Bayesian updating process as new information becomes available, and choose to continue or abandon investments based on updated beliefs (Bergemann & Hege, 1998; Gompers, 1995).

IMPLEMENTATION ISSUES IN REAL OPTIONS

Recent work on real options has drawn attention to potential implementation problems, especially in the abandonment of options. The reasons for difficulty in abandoning options can be traced to two observations. First, in contrast to financial options, real options do not have a predetermined exercise price and exercise date. This not only makes it difficult to precisely value the options, it also leaves firms with the imperative to identify and abandon projects that no longer have positive value. Especially when the incoming news about the project is negative, several studies have raised the possibility of irrational escalation of commitment (Staw, 1976), which makes it difficult to abandon investments (Coff & Laverty, 2001; Guler, 2003).

Second, the endogenous component of uncertainty, which allows firms to influence the final outcomes through their actions, may interfere with the discipline required to abandon options that are no longer valuable. Investors may prefer to modify project goals or standards instead of abandoning projects, in an effort to create a more favorable outcome (Adner & Levinthal, 2004). The effectiveness of firms in exercising real options may also be influenced by "rational overcommitment" (Adner, 2007), the tendency of individual managers to continue projects with the hope of improving the outcomes, especially when their personal interests are at stake.

Such implementation challenges may be more pronounced in the case of unsuccessful options than successful ones (Adner & Levinthal, 2004). It can be more straightforward to manage options that progress well, since signals of success are likely to be clearer than signals of failure. If the external feedback about the project is positive, the decision to invest further is less ambiguous. However, if the feedback about the project contains "bad news", firms have to rely on more subjective judgments or criteria to decide whether the problems are just temporary setbacks, require a new course of action, or are severe enough to warrant termination.

My interviews with venture capitalists confirmed that they experienced difficulty in terminating investment in unsuccessful companies, since they lack an explicit way of measuring companies' accomplishments from one round to the next. While milestones provide useful benchmarks to measure performance, they are often insufficient in evaluating unsuccessful companies. When a company is doing well, it reaches the milestones as planned, and the follow-on investment decision is fairly easy. However, companies rarely meet all of the milestones before they require additional cash. As such, milestones only provide incomplete, ambiguous, and often conflicting information about the company's progress. Therefore, VC firms' decision to invest further is based on subjective assessments. In such cases, VC firms often prefer to err on the side of investing more rather than less. In interviews, venture capitalists claimed that they stopped investment only if the company "woefully failed" to achieve the milestones:

> …Once you have invested first 3 million, you're pretty much hooked in order to make the deal work. If the deal suddenly doesn't work 12 months from now, those milestones have not been achieved, what do you do? Do you leave them and say, 'Forget it, you didn't meet my requirements so I won't give you money?' Most people say, 'No, let's try to fight and save the initial investment'.
>
> I don't think milestones are necessarily the ultimate achievement, but how well the company is [progressing] to achieve the milestones. It's not common that companies achieve what they set out to achieve. Entrepreneurs are overoptimistic and we factor that in. Rarely do they achieve or overachieve what they set out to achieve. So it really comes down to more of a subjective analysis of how well the company has [progressed] toward the achievement of objectives, and reduced or eliminated the risks that we tried to identify as issues for the investment.
>
> Let's stage that investment by milestones. But what's the point? You put in a million dollars if they put out the product, another million when they sign their first customer, sign so many customers. So my question is, what happens if they don't meet the milestone, do you walk away from it? If you do, what's the point of investing at the first place?[2]

As a result, management of options that progress well and those that do not progress as expected may present different, asymmetric challenges. Achievement of milestones is helpful in identifying and continuing options that are still valuable. In contrast, termination of options that are no longer performing well cannot solely rely on milestones but requires VC firms to use more subjective judgment and managerial discipline.

In the following section, I explore the patterns of sequential VC investments over time. I split my sample into subsamples of successful and unsuccessful companies and examine whether asymmetries in the management of the two subsamples indeed occur in a large-sample examination.

EMPIRICAL ANALYSIS OF VENTURE CAPITAL INVESTMENTS OVER TIME

Data

The empirical study examines VC investments in U.S. health care and life sciences companies founded between 1989 and 1993. I tracked the funding histories and exit events of these companies through 2004. The funding data were compiled from the VentureXpert database provided by Thomson Financial's Venture Economics.[3] These data have been used extensively in earlier research (Barry, Muscarella, Peavy, & Vetsuypens, 1990; Gompers & Lerner, 2000; Megginson & Weiss, 1991; Sahlman, 1990; Shane & Stuart, 2002; Sorenson & Stuart, 2001).

I used several sources to collect data on exit events. Data on the dates and valuation of IPOs were drawn from Ritter (2006), the Center for Research in Security Prices (CRSP), and Securities Data Corporation (SDC). I collected data on dates and valuations of acquisitions from the Mergers & Acquisitions Database of SDC. I limited the data to companies founded on or before 1993. Since a company typically takes 5–7 years to experience a liquidity event after the first VC investment (Fenn et al., 1997), limiting the data at 1993 provides an appropriate window to observe success or failure until 2004.[4]

In this study, I focused on VC investments in companies operating in health care and life sciences. Focusing on companies operating in similar or related industries enables a more precise comparison of VC investment practices in these industries. I chose to focus on health care and life sciences sectors, since these investments have the typical characteristics of investments under high uncertainty and skewed returns distributions (Scherer et al., 2000). I used the classification provided by VentureXpert in determining companies in these industries. Companies in this category correspond to Standard Industrial Classification (SIC) codes 283 (drugs), 382, 384, 385 (surgical, medical, and dental instruments; laboratory apparatus, analytical and optical; ophthalmic goods); 504 (professional and commercial equipment); 632 (accident and health insurance); 737 (computer programming and data processing); 801, 805, 806, 807, 808, 809 (health services), 836 (residential care), and 873 (research, development, and testing services).[5]

The final dataset includes investments by VC firms in each company. I organized the data into 393 VC firm-company pairs so that each VC-company pair appears only once. Each VC firm may appear more than once in the data if it has invested in multiple companies. Similarly, each company may appear more than once if it has more than one VC investor.

Analysis and Measures

In order to examine whether sequential investment practices differed between successful and unsuccessful investments, I split the sample in two subsamples, based on the final outcome. I assumed that companies that ultimately achieved a successful exit event would receive more positive indicators on average during the funding process and companies that ultimately failed would receive more "bad news" on average. Since VC firms achieve the highest returns through IPOs or acquisitions (Gompers & Lerner, 2000), I identified companies as successful if they experienced one of these two events as of 2004. I labeled the remaining companies as unsuccessful.

I then analyzed the number of rounds that each VC invested in these companies. As suggested earlier, VC firms acquire information about the prospects of each company throughout the investment process. Each round of investment comprises an opportunity to continue or terminate investment. If a company was eventually successful, venture capitalists that participated in more rounds took the right course of action by maintaining their options and exhibited more foresight in retrospect. In the case of companies that were not successful, the more effective strategy was to terminate investment as soon as possible. Firms that invested fewer rounds in unsuccessful companies interpreted and acted on negative information more swiftly than others.

Therefore, the dependent variable is *the number of rounds that a particular VC invested in a company*. The original data from VentureXpert overstates the number of rounds, since each distinctive date of cash infusion is counted as a new financing round even if the two dates are only days apart. A similar problem was also noted by Gompers and Lerner (2000), who found that the amount of overstatement is as high as 28% for biotechnology firms. In order to reduce this problem, I corrected the data such that two or more consecutive rounds listed within a 90-day period were treated as a single round.[6] This correction decreased the mean number of rounds per company from 3.76 to 2.21.[7]

I predicted the impact of two types of independent variables on the number of rounds invested. The first set involves indicators of the progress of the company in the funding process. I utilize the *number of patents* that the company acquired during VC funding as a proxy for the progress of the company. Patents are indicators of the intellectual capital developed by the venture (Shane & Stuart, 2002), and the number of patents is an indicator utilized by venture capital firms in funding (Baum & Silverman, 2004; Lerner, 1994). Prior research suggest that a portfolio company's patents are significant predictors of the likelihood of success (Stuart, Hoang, & Hybels, 1999) as well as the likelihood of failure (Shane & Stuart, 2002). The number of patents is collected from the USPTO's patent database. I calculated this measure as the count of patents that the company acquired after it received the first round of VC funding and before the final round of investment by the focal VC.

The second set of independent variables includes the characteristics of the VC firm. VC firms may exhibit differential levels of proficiency in evaluating companies and in deciding to continue or terminate each. As a result, the number of rounds invested in each company may vary as a function of VC firm characteristics. I proxied for the proficiency of the venture capital firm with three measures. The first is the *prior experience of the VC firm in health and life sciences investments*, calculated as the count of companies that the VC funded in these industries in the past 5 years. Venture capital firms with more experience in the industry will have an advantage in setting realistic milestones and assessing progress toward them. They will also have a better understanding of market signals and technological challenges, and better assess the company's progress (Sorenson & Stuart, 2001).

The second measure is the *geographic proximity* of the VC firm to the company. Geographic proximity not only facilitates the monitoring role of the venture capitalists through frequent interaction and office visits, but also aids in their advisory role, where venture capital firms provide expertise and resources (Gorman & Sahlman, 1989; Gupta & Sapienza, 1992; Lerner, 1995; Norton & Tenenbaum, 1993; Sorenson & Stuart, 2001). I measured geographic proximity with a dummy variable, which takes on the value of 1 if the VC firm operates in the same state as the company. The last measure is the VC firm's *prior IPO experience*, measured as the number of its portfolio companies that went public within the past 5 years, as a proportion of the total number the companies that it funded in the same period. The VC firm's prior success record is a proxy for its prior performance and its capabilities in investment management.

I included a number of control variables in the models. First, I controlled for the *first round in which the VC invested in the company*, since VC firms that started investment at early rounds may invest more rounds than their counterparts that joined the investment in later rounds. To illustrate, if the VC has invested in the company for the first time in the third round of financing, this variable will take the value of 3. Second, I controlled for the *total amount VC invested in company*, which may affect the total number of rounds invested. Third, I controlled for the *year at which the VC invested in the company,* by including dummy variables for 1989–2003. The year 2004 is the omitted variable. Note that industry variance is controlled for by limiting the sample to health and life sciences companies, and variance in the underlying quality of the companies is controlled for by creating subsamples according to realized outcomes.

Since the dependent variable (number of rounds) is a non-negative integer count, estimation with ordinary lest squares (OLS) is likely to produce biased estimates. I therefore estimated the number of rounds invested in each company using Poisson models. I also repeated the analyses with negative binomial models, and the results did not change. Multiple observations for the same company may create correlations between the error structure and the independent variables. Therefore, I estimated all models with the Huber-White-sandwich estimator of variance yielding robust standard errors, clustered on companies.

RESULTS

Table 1 shows the summary statistics and correlations for the variables in the study. The mean number of rounds that a VC invested in a company is 2.21; however, the number of rounds can go up to 11. Correlations between variables are low, reducing concerns for multicollinearity. Table 2 presents a comparison of summary statistics, by the final outcomes of investments. The number of rounds for successful and unsuccessful companies was similar. Successful companies acquire an average of 0.71 patents during funding, while unsuccessful firms acquire an average of 1.23 patents. The *t*-tests reveal that the difference between the two subsamples is not statistically significant, suggesting that companies may not differ significantly in their technological sophistication and the number of patents may not be a significant predictor of a company's ultimate success in the overall sample (Shane & Stuart, 2002).

Table 3 presents the results of the Poisson models predicting number of rounds in the overall sample and including success as an explanatory variable. Model 1 shows results with all four independent variables (number of patents, VC's experience in health care, geographic proximity, and VC's IPO experience). Models 2–5 add interactions of success with each of the independent variables, respectively. Overall, the results suggest weak explanatory power of independent variables in predicting success. The number of patents is positive, but only marginally significant. VC firms with more IPO experience appear to invest fewer rounds in each company. Two out of four interaction effects are significant. Accordingly, successful companies with more patents receive a larger number of rounds, as do successful companies, which are in close geographic proximity to the VCs. Among controls, investment amount is positive and significant.

Table 4 splits the sample into two subsamples of successful and unsuccessful companies, in order to examine whether funding criteria differ across the two subsamples. Models 1a and 1b present the baseline model with control variables only. Models 2a and 2b add the number of patents. Models

Table 1. Summary Statistics and Correlations ($N = 393$).

	Variables	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7
1	Number of rounds	2.21	1.59	1	11	1.00						
2	Number of patents	0.90	2.28	0	16	0.09	1.00					
3	VC's experience in health care	17.69	19.20	0	92	0.08	0.01	1.00				
4	Geographic proximity	0.50	0.50	0	1	0.03	0.03	0.01	1.00			
5	VC's IPO experience	0.04	0.06	0	0.33	−0.10	−0.02	0.06	−0.11	1.00		
6	Round VC first invested in company	2.22	1.79	1	10	−0.17	0.22	0.02	0.01	0.01	1.00	
7	VC's investment amount in company (million USD)	2.47	2.87	0.002	28	0.25	0.16	0.05	0.08	−0.10	−0.03	1.00

Table 2. Comparison of Summary Statistics for Subsamples of Successful and Unsuccessful Companies.

	Variables	Successful Companies ($N = 251$)		Unsuccessful Companies ($N = 142$)		*t*-Tests of Equality
		Mean	Std. Dev.	Mean	Std. Dev.	
1	Number of rounds	2.207	1.519	2.209	1.702	0.015
2	Number of patents	0.713	1.643	1.237	3.078	1.890
3	VC's experience in health case	18.808	19.897	15.727	17.796	−1.582
4	Geographic proximity	0.474	0.500	0.538	0.500	1.227
5	VC's IPO experience	0.043	0.062	0.026	0.048	−2.951*
6	Round VC first invested in company	2.059	1.572	2.510	2.085	2.246*
7	VC's investment amount in company (million USD)	2.412	2.673	2.565	3.197	0.506

*Significant at 5% level.

3a and 3b are the full models, with VC-firm characteristics (experience in health care, geographic proximity, and IPO experience).

Model 3a shows that the number of rounds invested in a company increases with the number of its patents in the sample of successful companies (Baum & Silverman, 2004). This model shows that VC-firm characteristics are not significant in explaining the number of rounds invested in successful companies. Level of prior experience, geographic proximity to the company, or IPO experience do not significantly influence the investment policies in the case of successful investments. Among control variables, the amount of investment is positive and significant.

Model 3b shows different patterns from the analysis of the successful subsample. First, number of patents is not a significant predictor of rounds invested in the case of unsuccessful companies. In contrast, all three firm-level characteristics are significant. VC firms with more prior experience in health care seem to invest more rounds in unsuccessful companies. VC firms that are located in closer geographic proximity, and those that have more IPO experience, invest systematically fewer rounds in unsuccessful companies. The amount of financing is positive and significant, as in the successful sample.

I conducted Chow tests to examine whether the coefficient estimates for the explanatory variables are significantly different across the two subsamples.

Table 3. Results of Poisson Models Predicting Number of Rounds Invested.

	(1)	(2)	(3)	(4)	(5)
Number of patents	0.032^{+}	0.005	0.033^{+}	0.029	0.033^{+}
	(0.020)	(0.015)	(0.019)	(0.019)	(0.019)
VC's experience in health care	0.002	0.002	0.005*	0.002	0.002
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Geographic proximity	−0.002	−0.011	−0.008	−0.223*	−0.003
	(0.061)	(0.062)	(0.061)	(0.096)	(0.061)
VC's IPO experience	−1.426**	−1.340*	−1.424**	−1.530**	−2.066*
	(0.522)	(0.521)	(0.523)	(0.544)	(0.953)
Round VC first invested in company	−0.037	−0.030	−0.038	−0.034	−0.037
	(0.033)	(0.033)	(0.034)	(0.034)	(0.034)
VC's investment amount in company	0.054**	0.052**	0.055**	0.053**	0.054**
	(0.016)	(0.015)	(0.016)	(0.016)	(0.016)
Success	−0.121	−0.188^{+}	−0.043	−0.291*	−0.146
	(0.102)	(0.108)	(0.115)	(0.121)	(0.113)
Success × patents		0.066**			
		(0.025)			
Success × VC's experience			−0.004		
			(0.003)		
Success × geographic proximity				0.345**	
				(0.119)	
Success × VC's IPO experience					0.877
					(1.145)
Investment year dummies	Sig.	Sig.	Sig.	Sig.	Sig.
Constant	−0.228	−0.069	−0.244	0.005	−0.229
	(0.179)	(0.127)	(0.177)	(0.179)	(0.179)
Observations	393	393	393	393	393
Log likelihood	−640.35	−637.69	−639.71	−637.55	−640.19

Robust standard errors in parentheses.
$^{+}$Significant at 10%.
*Significant at 5%.
**Significant at 1%.

The tests suggest that the difference of the coefficients is significant. The χ^2 for each variable are as follows: 8.67 for patents ($p<0.05$), 13.59 for VC's experience in health care ($p<0.001$), 22.30 for geographic proximity ($p<0.000$), and −2.64 for VC's prior IPO experience ($p<0.01$).

The results are robust to a number of sensitivity analyses. First, I excluded companies with more than 11 patents, in order to examine whether these observations act as outliers. Second, I controlled for the number of patents

Table 4. Results of Poisson Models for Successful and Unsuccessful Companies.

	Successful Companies			Unsuccessful Companies		
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)
Number of patents		0.078** (0.022)	0.075** (0.023)		0.007 (0.019)	0.009 (0.017)
VC's experience in health Care			0.000 (0.002)			0.007** (0.002)
Geographic proximity			0.116 (0.073)			−0.230** (0.087)
VC's IPO experience			−1.054 (0.659)			−2.642** (0.965)
Round VC first invested in company	−0.019 (0.058)	−0.022 (0.059)	−0.018 (0.064)	−0.038 (0.026)	−0.041 (0.029)	−0.046 (0.032)
VC's investment amount in company	0.049* (0.022)	0.041* (0.019)	0.039* (0.019)	0.065** (0.023)	0.065** (0.023)	0.061** (0.022)
Investment year dummies	N.S.	N.S.	N.S.	Sig.	Sig.	Sig.
Constant	0.330 (0.379)	0.421 (0.382)	0.419 (0.374)	−0.045 (0.102)	−0.077 (0.123)	0.102 (0.133)
Observations	251	251	251	142	142	142
Log likelihood	−410.06	−404.36	−402.59	−232.32	−232.27	−226.07

Robust standard errors in parentheses.
*Significant at 5%.
**Significant at 1%.

that the company acquired before the start of the funding process, since VCs may use this information to screen potential investment opportunities. Third, I controlled for the total amount of financing that the company received from all VC firms. Fourth, I used negative binomial models instead of Poisson. The results were robust in each case. Finally, I ran logit models predicting likelihood of success, using number of rounds and independent variables as predictors. These analyses suggest that none of these variables are significant predictors of success in the sample, consistent with the descriptive statistics presented in Table 2. This result is interesting, because it suggests that the differences in the financing process of successful and unsuccessful companies are likely due to management of these companies, rather than objective differences that influence the likelihood of success.

DISCUSSION

The results suggest an interesting asymmetry in the management of options that perform well over time, and those that do not. Interim indicators of progress, such as patents, seem to be significant predictors of VC investment practices in the case of successful companies. However, they are not significant in predicting investment practices for unsuccessful companies. In contrast, while VC characteristics such as industry experience, geographic proximity, and IPO experience do not significantly affect investment practices in the case of successful companies, all three are significant predictors of practices in unsuccessful ones.

These findings provide some support for the idea that milestones and interim indicators of progress only add significantly valuable information when the company is performing well. In such cases, signals of success are easy enough to interpret. However, when the company is not doing well, indicators, such as patents, do not provide clear guidance for investment practices, especially for termination. As suggested by the VC interviews, firms can continue funding despite some negative feedback, or in some cases, change goals of the project, or even its standards for success. Therefore, termination is not a straightforward decision:

> The problem is that you can never define the milestones at time 0. This is more of a problem in early stage investment. By the time of the next cash infusion, business may change so that milestones are not so relevant anymore. All the trouble that the firm took upfront is a waste of time in that case. For example, if the company is to release a new product, the milestone may be a successful launch. But maybe the product changes, or strategy changes, or other things that were not important before become more important. The original milestones don't apply. None of us are smart enough to see what these critical points may be.

Since termination decisions appear to be more complex and subjective than continuation decisions, firm-level differences may be significant predictors of firm actions in the case of unsuccessful investments rather than successful ones. Since management of successful investments is relatively more straightforward, firms do not seem to differ in the management of these investments. However, signals of failure are more ambiguous than signals of success, and differences in how firms manage failing investments are more pronounced. Capabilities in accurately forecasting an investment's prospects are likely to vary across firms (Makadok & Walker, 2000), as well as the discipline in managing them.

The results suggest that firms that are in close geographic proximity to their portfolio companies, are likely to invest fewer rounds in unsuccessful companies. This result is consistent with prior research which suggests that the monitoring and evaluation functions of the VC firms are facilitated when it is located in short physical distance to its companies (Sorenson & Stuart, 2001). Similarly, VC firms that have more prior experience with successful companies invest fewer rounds in unsuccessful companies. It seems that prior IPO experience helps improve the firm's capabilities in differentiating between successful and unsuccessful companies.

A surprising finding of the study is that VC firms with more prior experience in the industry invest more rounds in unsuccessful companies, and do not invest significantly more rounds in successful ones. Given that prior experience should also lead to improvements in firm capabilities in evaluating and managing investments (e.g., Zollo & Winter, 2002), this result presents a puzzle. It is possible that firms with more prior experience are more exposed to the problem of endogeneity, in which the firm changes project targets and standards in order to "save" the option rather than terminating it (Adner & Levinthal, 2004). Prior experience may lead firms to exhibit higher overconfidence and to a misplaced belief that they can turn companies around, even when external signals suggest otherwise. However, the question remains: Under what conditions do firm characteristics, such as prior experience, become a burden by leading firms to overinvest in existing options, instead of adding value? Further research is needed to answer this question.

The study contributes to the real options literature by demonstrating how managerial challenges may present themselves differently in the case of successful and unsuccessful options. Normative literature on real options has focused mainly on the adoption of real options logic in organizations and methods of valuation to be used (e.g., Dixit & Pindyck, 1994). Recent work has pointed out the possibility of managerial challenges in the implementation of the real options logic over time, especially when the investment is not performing well (Adner & Levinthal, 2004; Coff & Laverty, 2001). This study provides empirical support for this argument in the venture capital industry. It demonstrates asymmetries in the management of options that perform as expected and those that do not. While management of successful options requires careful attention to objective signals of success, management of unsuccessful options requires subjective judgment about whether to continue or terminate investments. In consequence, firm-level differences are more pronounced in the management of unsuccessful options, and may potentially affect firm performance.

The study presented in this paper suffers from several limitations. First, it examines investment decisions according to the observed outcome of the investment, after the fact. The assumption is that the interim signals of the company's progress will on average accurately represent the outcome of the investment. However, these signals may not be uniformly distributed over the duration of the investment. A more detailed analysis of the company's progress toward milestones over time can provide a more complete picture of the VC investment process. Moreover, I do not possess more detailed information about the companies' characteristics, such as founders' human and social capital (Shane & Stuart, 2002). While it would be ideal to control for all characteristics of the companies, I attempted to reduce concerns of unobserved heterogeneity through sensitivity analyses.

Second, the study focuses on the investment policies with respect to observed outcomes. As such, it does not take into account the potential costs of terminating investments too early. These two costs can be thought of as Type I/Type II errors in research. While overinvesting in a project with declining prospects clearly has costs (Type I error), terminating projects that might otherwise be profitable also imposes opportunity costs (Type II error). In reality, the decision to continue a project might be characterized as a tradeoff between these two potential costs (Coff & Laverty, 2007; Powell, Puranam, & Singh, 2002). Unfortunately the data does not allow a study of what might have happened to the terminated companies had the investment been continued. However, the interviews suggests that VC firms prefer to err on the side of investing more, since the downside is limited to the investment but the upside is much higher.

Despite these limitations, the study takes a preliminary step in understanding asymmetries in the management of successful and unsuccessful investments. The findings of this study may have implications for other investment situations that are broadly characterized by high uncertainty and skewed distribution of returns (Scherer et al., 2000), such as development of a pharmaceutical drug or a new product. While each of these investment situations may have unique characteristics, they are similar in that few investments generate blockbuster returns while a vast majority results in a loss or modest returns. Received wisdom about these industries emphasizes the initial search for blockbuster investments in order to increase overall portfolio performance. However, this study suggests that management of unsuccessful investments could also be a critical component of performance. First, unsuccessful investments comprise a large proportion of all investments made. Second, the ability to find blockbuster investments also increases with firms' effectiveness in abandoning unsuccessful investments and shifting resources to better opportunities. Third, since uncertainty at the time of initial investments is very high, the ability to spot winners may be limited. As a result, capabilities in managing ongoing investments may be as important a component of performance as initial selection of investments.

Since investment decision making is among the primary activities of venture capitalists, problems of implementation are less likely to be a function of poor managerial effort or lack of attention to decision making. VC firms have high incentives to ensure quality of investment decisions and employ multiple safeguards to do so (Fenn et al., 1997; Gompers & Lerner, 2000). Moreover, venture capitalists are removed from the operations of their portfolio companies and are thus likely to have more objective assessments compared to managers in other organizations (Coff & Laverty, 2007). Consequently, the results here might represent the upper bound on the quality of decisions in a typical organizational situation and the observed patterns in the management of the real options logic may be generalizable to other organizations.

NOTES

1. In the discussion of the venture capital industry, I use the term ''firm'' solely to refer to venture capital firms and ''company'' to refer to portfolio companies (entrepreneurial ventures).
2. The quotes are from my interviews with a sample of venture capitalists. The identities of interviewees are not disclosed, due to confidentiality agreements. More information about the interviews can be found in Guler (2003).
3. The data in the VentureXpert database includes ''standard U.S. venture investing'', where the company is domiciled in the U.S., at least one of the investors is a VC firm, VC investment is a primary investment, and it entails an equity transaction. I only included investments by VC funds, as explicitly identified by the database.
4. Even though some companies may exit in shorter time, allowing 11–15 years to observe exit events reduces the likelihood of right censoring before the exit event takes place.
5. The VentureXpert classification does not map onto the SIC codes perfectly. So some SIC categories (e.g., computer programming and data processing) do not appear in their entirety, but only in relation to health care and life sciences.
6. The reason for choosing 90 days as a cutoff point is that most term sheets signed between entrepreneurs and investors at each round of financing specify a maximum 90-day closing date window, during which investors can schedule their cash infusions to the portfolio company. Typically, if there are more than 90 days between two capital infusions, the second infusion is considered a ''new'' round, and is subject to new terms.
7. This correction does not change the results of the analyses.

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