Innovation Outside Firm Boundaries: A Real Options Perspective on Appropriability, Commercialization Strategies and Firm Performance

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Dedication

This work is dedicated to my loving and supportive husband Joseph; my precious daughters Catherine and Linette; and my mother and father who always believed I could.

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Abstract

This dissertation focuses on the conditions under which innovating firms may employ external commercialization strategies to appropriate value from their innovations and enhance firm performance. Specifically, I examine the relationship between appropriability conditions of intellectual property protection, complementary assets and uncertainty, and the firm's decision to commercialize innovations externally. Applying real options theory to a firm's innovation strategy, I hypothesize that external commercialization strategies mediate the effect of appropriability conditions on firm performance. Hypotheses tests are conducted on a sample of more than 1600 firms and 300 external commercialization agreements in the manufacturing sector. Notwithstanding the overall lack of support for these hypotheses, there remains potential for making a contribution to the innovation literature. First, the integration of real options theory and the appropriability framework offers a theoretical extension of both literatures. Second, results of post-hoc tests indicate that some relationships do exist and further investigation is warranted.

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CHAPTER 1 INTRODUCTION

Introduction

Firms in the US spent $330 billion on innovation in 2008 (NSF, 2010), with each firm aiming to benefit from their investment. Indeed, strategic management literature points to innovation as a source of competitive advantage and one explanation for why some firms outperform others (Hamel, 2000; D'Aveni, Dagnino & Smith, 2010). Overall support for the link between firm innovation and performance contributes to the view that firms will benefit from investing in innovation (Crossan & Apaydin, 2010; Rosenbusch, Brinckmann & Bausch, 2011). However, innovating firms do not always realize the value generated by investing in innovation (Arrow, 1962; Schumpeter, 1950). Some of the value generated by investing in innovation may be absorbed by other firms including imitators, suppliers, customers or even partners (Teece, 1986). Thus, it appears that it is not sufficient for firms simply to invest in innovation. To realize performance advantages, it is also necessary for innovating firms to appropriate the value generated by this investment (Winter, 2006).

Open innovation has been proposed as one strategy firms can use to increase appropriation from their investment in innovation (Chesbrough, 2003; Pisano & Teece, 2007). Open innovation capitalizes on the view of innovation as commercialized invention (Schumpeter, 1934). It recognizes that invention and commercialization are not only separate functions of innovation but can be performed by different firms (Teece, 1986). Open innovation is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Chesbrough, Vanhaverbeke & West, 2006: p. 1).[1] Thus, firms stand to gain from *both* searching for external sources of

[1] Although the terms are similar, open source software and other types of open systems are different than open innovation and lie outside the scope of this dissertation. *Open source software* (OSS) is continuously re-invented by

technology and intellectual property that can be brought inside the firm to be developed *and* actively searching for external channels to market for technology and intellectual property that was developed inside the firm but may appropriate additional value if commercialized outside the firm (Rothaermel & Alexandre, 2009; Jacobides, Knudsen & Augier, 2006). It is the latter strategy, to appropriate value from external commercialization of innovation, which is of primary interest in this dissertation.

I define external commercialization as an organization's deliberate commercialization of technological knowledge to an outside organization, exclusively or in conjunction with internal commercialization (Chesbrough, 2003; Lichtenthaler, 2005; 2009). That is, external and internal commercialization strategies are not mutually exclusive for any one innovation or across the firm's innovation portfolio. Mechanisms for external commercialization include but are not limited to outlicensing, spin outs and patent sales (Chesbrough, 2003). Economic estimates place firm revenue from industrial technology licensing at more than $60 billion in the United States and $100 billion worldwide (Arora & Gambardella, 2010a; Robbins, 2009).

Exemplars of the external commercialization strategy include firms such as Texas Instruments which earns up to half its net income from licensing revenues in some years (Chesbrough & Garman, 2009). Similarly, Qualcomm opted for a business model of licensing its technology to device makers rather than manufacturing handsets in competition with them (Pisano & Teece, 2007). IBM and Dow Chemical have undertaken aggressive programs to monetize their rich patent stocks through outlicensing. IBM collects as much as $1billion, over 15% of its R&D expenditure, in licensing revenue annually (Chesbrough & Garman, 2009).

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a developer community that has full access to the source code. As a condition of use, the developers must make their enhancements to the source code freely available to others in the community (The Open Source Initiative). This open source model promotes widespread value creation and knowledge transfer among the community of interest, while effectively precluding value capture by any one member of the community (Alexy & Reitzig, 2012; Vitharana, King & Chapman, 2010).

Xerox is an example of a firm that struggled to commercialize technologies developed in its PARC research center and eventually adopted a spin out strategy to commercialize its technologies. Adobe, 3Com and SynOptics are examples of successful companies spun out of Xerox technology (Rosenbloom & Chesbrough, 2002). Likewise, Lucent and British Telecom have leveraged their technology with a spin out strategy (Chesbrough & Garman, 2009). External commercialization strategies are also used by smaller firms. Studies of firms in the biopharmaceutical industry confirm that external commercialization through licensing can be a viable strategy for firms that do not vertically integrate into manufacturing and marketing (Kollmer & Dowling, 1994; Walter, 2012).

Research Questions

The literature investigating firm motivations for external commercialization focuses largely on the influence of intellectual property protection on a firm's propensity to license its technology (Arora, Fosfuri & Gambardella, 2004). Mixed empirical results, combined with insights from the seminal work of Teece (1986), laid the groundwork for researchers to investigate additional conditions that would affect a firm's ability to appropriate value from innovation. Teece (1986) proposed that together with intellectual property protection, a firm's control over complementary assets and uncertainty related to market demand and technological trajectories influenced whether a firm was likely to appropriate value from its innovation. Subsequent research has investigated the influence of these appropriability conditions on the firms licensing activity (e.g. Arora & Fosfuri, 2003; Ceccagnoli, 2009; Fosfuri, 2006). Yet, these studies do not link external commercialization with firm performance.

Given the important contribution of the appropriability framework (c.f. Research Policy 2006 special issue) and the body of literature investigating firm licensing behavior (c.f. Arora &

Gambardella, 2010a for a review), it is surprising that no study has yet conducted an empirical investigation of the performance outcomes of external commercialization in the context of the appropriability framework. In the only study that I am aware of that links external commercialization to firm performance, the influence of the appropriability conditions were not investigated (Walter, 2012). Moreover, extensions of the appropriability framework propose that firms may deploy external commercialization to strategically reposition themselves with respect to appropriability conditions and thus improve their performance outcomes (Jacobides et al., 2006; Pisano & Teece, 2007). However, the empirical work to support this proposition has not yet been undertaken.

At the same time external commercialization appears to be underutilized in practice (Chesbrough, 2003; Pisano & Teece, 2007). Despite the anecdotal evidence and billions of dollars in licensing revenue already collected by firms, a closer examination reveals that a limited number of firms account for the majority of external commercialization activity and much of it occurs between affiliated companies (Arora & Gambardella, 2010b; Robbins, 2009). Although proponents of external commercialization provide a convincing argument for more firms to adopt this strategy, empirical evidence to identify the conditions under which an external commercialization decision results in superior firm performance is currently absent.

This opportunity to increase our understanding of external commercialization as a strategy to enhance appropriation from innovation and firm performance led me to investigate two research questions:

1. What conditions influence the extent to which a firm engages in external commercialization?

2. Does external commercialization influence firm performance?

Another challenge that has stymied progress in the literature is a theoretical foundation for external commercialization as a strategy to enhance competitiveness and firm performance (Arora & Gambardella, 2010a; Chesbrough et al., 2006). Research investigating external commercialization (specifically outlicensing) adopts a transaction cost economics perspective to explain why technology is commercialized inside or outside the firm (Williamson, 1991). Although this provides insights on the boundaries of the firm, it does not contribute to explanations of why some firms outperform others and thus has limited value in guiding firm strategy.

Theoretical Framework

Accordingly, I draw on real options theory to explain both the external commercialization decision and its effect on firm performance. The commercialization decision, like other decisions in the innovation process, is characterized by relatively high technical and market uncertainty (McGrath, 1997). Real options theory has been applied to previous innovation research to because it is a useful approach to decision making under uncertainty (McGrath, 1997; McGrath, Ferrier & Mendelow, 2004). Real options involve investments in real assets which create the right, but not the obligation, to take an action in the future (Amram & Kulatilaka, 1999). For example an investment in research and development creates an underlying asset in technological knowledge. This provides the firm with an option to further invest commercialization of the innovation (Bowman & Hurry, 1993). Thus, I apply real options theory to commercialization of innovation; conceptualizing external commercialization as a real option on the investment in innovation.

Although real options theory provides a general theoretical approach to decision making under uncertainty, more specific criteria are required to apply real options theory as a useful

heuristic for discrete decisions - such as the commercialization of innovation. Building on the foundations in the literature, I draw on the appropriability framework (Teece, 1986) to supply these criteria. Teece (1986) seminal article, commonly referred to as *Profiting from Innovation* introduced the appropriability framework to identify conditions under which an innovating firm could appropriate value from its own innovation. The framework proposed that a firm would capture the value of an innovation based on; 1) its control over complementary assets (specific or generic), 2) appropriability regimes (the extent of IP protection), and 3) market timing (technical and market uncertainty). Through applying real options theory and the appropriability framework to the investigation of external commercialization and firm performance I aim to make the following contributions.

Contributions

The principal contribution of this research is to extend the literature on external commercialization to include the effects on firm performance. This contribution is enhanced by integrating the appropriability framework to provide the context for the investigation. The extant literature often studies external commercialization in the context of the appropriability framework, but we do not know the effects on firm performance under these conditions. The only study to date examining external commercialization and firm performance does not account for appropriability conditions (Walter, 2012).

The contribution is further augmented by the large scale empirical design of the study. I investigate more than 300 external commercialization agreements across 1600 firms from multiple industries in the manufacturing sector. This design is meant to achieve generalizability beyond single industry studies (Fosfuri, 2006) or samples that include only firms that engage in external commercialization (Walter, 2012).

A second contribution arises from the application of real options theory to external commercialization strategy. Extension of real options theory from innovation in general to external commercialization in particular, provides a strategic focus to the study of external commercialization (McGrath, 1997). Real options theory goes beyond the transactions cost explanation of the boundaries of the firm to provide a performance based rationale for external commercialization. In addition, real options theory has been previously recommended as a relevant theoretical lens for viewing external commercialization strategies (Pisano & Teece, 2007). However this has not been systematically applied in the literature to date.

This dissertation also aims to inform practitioners on several fronts. Foremost, it has potential to provide empirical evidence to support recommendations for firms to use an external commercialization strategy. In the absence of a link between external commercialization and firm performance, this evidence does not currently exist. It also provides real options logic to show that commercialization decisions may be improved when external commercialization is included in the heuristics. These contributions may help practitioners garner support for external commercialization in their organization.

In summary, I have provided an overview of the challenges firms face in appropriating value from their investment in innovation. I further identified external commercialization as a potential strategy to enhance appropriation from innovation and firm performance, and pointed to the absence of empirical evidence for this proposition. Finally, I identified the contributions that could be made through investigation of the focal research questions in this dissertation. To conclude Chapter 1, I offer definitions and terms and outline the organization of the dissertation.

Definitions and Terms

Appropriation, appropriability and appropriability regime. In the context of this paper *appropriation* refers to the distribution of value generated from the innovation among the innovating firm and other entities (Ceccagnoli, 2009; Teece, 1986; Winter, 2006). These entities include but are not limited to rival firms, new entrants, suppliers or customers (Pisano & Teece, 2007). This is consistent with the industrial economics approach to quasi-rent distribution at the industry level (Amit & Schoemaker, 1993; Porter, 1980). In contrast, the appropriation construct in resource based theory (RBT) is often firm-level rather than industry level. The RBT literature examines how value captured by the firm is distributed among firm stakeholders such as employees and shareholders according to relative bargaining power (Coff 1999; 2010). In this paper I refer to the value appropriated by the innovating firm relative to other firms (Amit & Schoemaker, 1993; Porter, 1980), rather than to value appropriated by stakeholders relative to the firm (Coff 1999, 2010).

The term *appropriability* refers to the extent to which the entity that generated the value can capture it. For example, the appropriability framework (Teece, 1986) establishes the conditions that influence the degree to which the innovating firm can capture the value created from innovation, relative to other entities (Ceccagnoli, 2009; Teece, 1986; Winter, 2006).

Appropriability regime is a specific means of appropriability and refers precisely to "the protection afforded the innovator by intellectual property protection and natural barriers to imitation" (Pisano & Teece, 2007: p. 279). As the name implies, the appropriability regime influences which entities ultimately capture significant shares of the available profits from innovation (Nelson, 2006; Teece, 2006). A strong appropriability regime offers relatively high protection for innovators and facilitates value capture by the innovating firm. A weak

appropriability regime affords relatively low protection for innovators and enables value capture by other firms in the industry (Cohen, Nelson & Walsh, 2000).

External commercialization. I define external commercialization as an organization's deliberate commercialization of technological knowledge to an outside organization, exclusively or in conjunction with internal commercialization. The definition is built from several terms defined in previous literature. The first term, outward open innovation, originates in Chesbrough's (2003) discussion of open innovation and refers to "internal ideas [that] can also be taken to market through external channels, outside the current businesses of the firm, to generate additional value" (2003: p. xxiv). A related term, outbound open innovation, has been defined as "[external] commercialization of technological knowledge exclusively or in addition to its internal application" (Lichtenthaler, 2009: p. 318). The last term, external knowledge commercialization, is described as "an organization's deliberate commercializing of knowledge assets to another independent organization involving a contractual obligation for compensation in monetary or non-monetary terms" (Lichtenthaler, 2005: p. 233). By consolidating the definition of the focal construct from prior terms and definitions, I build cohesion around the construct and meaning of external commercialization.

Open innovation. Open innovation is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation" (Chesbrough, 2006: p. 10).[2] Technology transfer out of research institutions into the for-profit sector could be considered a specific type of open innovation (Mowery, 2011; Sampat, 2006). However, these special cases are not the focus of this research. In this study, I

[2] Similar to open source software, the philosophy of *open science* is to publish new discoveries so that the scientific community can access them freely to further advance knowledge. It is possible to conceive of open source and other open systems as a specific type of open innovation that includes value creation but not value capture (West, 2006).

consider open innovation among profit seeking firms whose usual business includes invention and commercialization of technological knowledge.

Real option. Real options involve investments in real assets which create "the right, but not the obligation, to take an action in the future" (Amram & Kulatilaka, 1999: p. 5).

Organization

This dissertation is organized in five chapters. This chapter introduced the purpose of the study and laid the foundation for investigation of external commercialization through the lenses of real options theory and the appropriability framework. Chapter 2 is divided into three sections. The first section provides a literature review of real options theory and introduces the appropriability framework. The second section of Chapter 2 applies real options theory to develop a model which explains the factors that influence external commercialization and the consequences for firm performance. The final section of Chapter 2 elucidates four testable hypotheses for this model. Chapter 3 outlines the research method including the sample, measures, and statistical tests of the hypotheses. Chapter 4 reports the results of the analysis. Finally, Chapter 5 offers a discussion of the salient results, contributions, limitations and future research opportunities.

CHAPTER 2 LITERATURE REVIEW

The first section of this chapter provides a literature review of real options theory. Then real options theory is applied to the focal construct - external commercialization of innovation. Next, the appropriability framework is introduced to develop a model of external commercialization based on real options theory. Finally, the hypotheses explicate the relationships between the appropriability framework, external commercialization and firm performance.

Real Options

Real options theory extends from its origins in financial options (Black & Scholes, 1973). A financial option is an instrument that allows an investor to make a small investment in return for the right, but not the obligation, to make a subsequent investment (in the underlying security) in the future (Black & Scholes, 1973). The option may be held until future conditions turn favorable, i.e., the price of the underlying security rises above the option exercise price. At this point the option may be exercised for a profit. However if future conditions are unfavorable, i.e., the price of the security falls below the option exercise price, an investor may let the option expire and abandon the investment. In this scenario losses are limited to the cost of the option (Black & Scholes, 1973). Thus, an option has value because it allows the owner to participate in upside potential while limiting downside losses (Black & Scholes, 1973). This simple and attractive investment principle led scholars to extend options theory to investments in real assets (Myers, 1977; Dixit & Pindyck,1994; Trigeorgis, 1996).

Real options involve investments in real assets such as research, development and commercialization of innovations (Bowman & Hurry, 1993; McGrath, 1997). Similar to financial options, a real option is “the right, but not the obligation, to take an action in the future” (Amram

& Kulatilaka, 1999: p. 5). A real option is created through an initial investment in a real asset that positions the firm to take advantage of an opportunity in the future (Bowman & Hurry, 1993). There are several types of options including growth options, flexibility options, and nested options. I describe each of these in the next section.

Types of Options

Growth options. Growth options allow managers to stage investments such that smaller investments can be made initially with the option to increase commitment and expand the project as success unfolds (Amram & Kulatilaka, 1999). For example, joint venture agreements that contain explicit provisions for buying additional equity are considered growth options (Reuer & Tong, 2005). Foothold investments for market entry are also considered growth options (Miller & Folta, 2002). Some growth options are considered platform investments, or learning investments. For example, basic research and development, while not providing a direct payoff in the exploratory research stage, creates a platform for development of future applications which may be exploited at a later stage with further investment (Kim & Kogut, 1996). Additional examples of growth options include incremental addition of manufacturing capacity, product line extensions and geographic expansion (Trigeorgis, 1996).

Flexibility options. Flexibility options enable managers to deploy the investment in more than one way. A classic example is a power plant that can use alternative fuel sources such as coal, oil or natural gas. The source of fuel can be changed according to the prevailing price of fuel (Copeland & Antikarov, 2001). Platform investments in basic technologies, treated as a growth option above, may also be considered a flexibility option because basic technology, for example GPS, can often be applied in different product markets (Kim & Kogut, 1996).

Accordingly, alternatives for internal or external commercialization of innovation may be considered a flexibility option (Vanhaverbeke, Van de Vrande, & Chesbrough, 2008).

Nested options. Nested options, sometimes referred to as compound or embedded options, emerge as a chain of options in which one investment opens additional options for future investments (Amram & Kulatilaka,1999). New product development processes are based on a series of nested options with successive decision points (gate) representing the exercise of an option to begin the next phase (stage) - or discontinue the project (MacMillan, van Putten, McGrath & Thompson, 2006). However, nested options are not always specified ex-ante. Knowledge investments such as those in basic research are commenced with the options for continuing the research emerging only as the project advances (Kogut, 1991). The option of external commercialization may also be considered a nested option in that it can only be considered subsequent to invention.

To illustrate: research and patenting of one specialty chemical compound (platform investment) may yield five options for new product applications (flexibility option). Managers may decide to exercise the option for further product development (nested option) for two of these five options. At a later stage one of these options may be commercialized as a new product (growth option). After this product is established in core markets managers may choose to make further investments in product line extensions or new markets (growth options). Meanwhile mangers may hold the second option in the development stage foregoing commercialization at the present time. The third option may be licensed to another firm for application in a specific market (nested/flexibility option), while the remaining two options are abandoned. This example illustrates how the value of a real option increases as the chain of options magnifies the variance in outcomes on the upside while limiting the downside. Options seem particularly valuable for

innovation investments in which technological and market uncertainty are high, specific outcomes are difficult to specify ex-ante, and managerial discretion to exercise, hold, abandon or create new options is critical to success (Amram & Kulatilaka,1999; McGrath, 1997).

Real options are sequential investments that can be made under conditions of uncertainty. In keeping with its core principle in finance, a real option has value because it enables the firm to capture upside potential while limiting downside losses (Lee, Peng & Barney, 2007; McGrath, 1999; Myers, 1977). The value of a real option is built on three fundamental principles: irreversibility, uncertainty and managerial flexibility (Dixit & Pindyck, 1994; Kogut & Kulatilaka, 2001). Table 2.1 compares real and financial options with respect to these principles. Real options are characteristically less reversible and more uncertain than financial options and the managerial flexibility is more complex due to the nature of nested options, which are not available in financial options. In the next section, I review the real options literature within the structure of the principles of irreversibility, uncertainty and managerial flexibility.

Irreversibility

The first principle framing real options value is irreversibility. Unlike financial assets that can be readily traded in secondary markets, investments in real assets tend to be irreversible (Myers, 1977). Irreversibility is the extent to which the "investment expenditures are sunk costs … and cannot be recovered" (Dixit & Pindyck, 1994: p. 8). Because managers are reluctant to incur sunk costs, irreversibility leads firms to delay investment in new projects and hold onto existing projects longer (Kogut & Kulatilaka, 2001). Indeed, McGrath & Nerkar (2004) found that when larger commitments had been made in an existing area, firms were less likely to pursue new areas. This inertia may be mitigated by adopting a real options approach to managing

Table 2.1 Comparison of Financial Options and Real Options

	Financial Options	Real Options
Uncertainty	Financial options have a fixed expiration date and exercise price ex-ante. The price of the underlying security and return on the option investment is known at the time the option is exercised. The uncertainty with respect to a financial option is limited to the price changes of the underlying security (above or below the exercise price), which can be monitored transparently with accuracy (Myers, 1977).	Investments in real options do not have a fixed expiration date. The expected return on investment at the time the option is exercised can be forecasted but remains uncertain. The uncertainty surrounding real options includes dynamic and complex environmental factors. The impact of these factors on the return on investment over time is uncertain (Amram & Kulatilaka, 1999; Myers, 1977).
Managerial Discretion	Financial options are created when an option on an underlying security is purchased. Financial options may be held until exercised for a profit, held until expiration (abandoned) or sold in the secondary market (Black & Scholes, 1973, Myers, 1977).	Real options are created when firms make an initial investment in a real asset. Real options may be fully exercised by making a full investment and completing the project. Real options may also be exercised by making an incremental investment, in effect creating a subsequent option. Real options can be held for an indeterminate time period or abandoned with the sunk cost limited to the investment to date (Dixit & Pindyck, 1994; Trigeorgis,1996).
Irreversibility	Investments in financial options are reversible because they are actively traded in secondary markets (Black & Scholes, 1973).	Investments in real options tend to be irreversible because there is not an active secondary market. These investments may also be firm-specific or ambiguous making them idiosyncratic to the investing firm and trading terms difficult to determine. Therefore investments in real options are largely construed as sunk costs (Dixit & Pindyck, 1994).

investments in full scale projects, firms using real options make small initial investments followed by a series of incremental investments prior to making a final commitment with a large investment. This sequencing of investments allows the firm to initiate more new projects with a small sunk cost in each one (Bowman & Hurry, 1993). Because the sunk costs are limited, managers may also be more willing accept sunk costs of unsuccessful projects, and allow funds to be reallocated to follow on investments in projects with greater prospects (McGrath, 1997). Based on the assumption of irreversibility, real options predicts that firms will start more and cancel more projects and make small investments sequentially (Bowman & Hurry, 1993; Adner & Levinthal, 2004b).

Bowman & Hurry (1993) extended these predictions to inferences for firm performance proposing that: 1) firms using the sequential approach to investing would outperform those that make single large investments or unrelated small investments, and 2) firms with larger and more diverse options portfolios would perform better across varying environmental conditions, than those with a narrower set of options (Bowman & Hurry, 1993). Hurry, Miller & Bowman (1992), found evidence of real options investment patterns among Japanese investors in technology ventures. These investors had larger portfolios, and made smaller investments followed by increasing stakes over time. In contrast, their American counterparts made large investments and quick exits; however performance was not measured in this study (Hurry, Miller & Bowman, 1992). Folta (1998) also found that biotech firms favored investments in growth and flexibility options such as joint ventures over full commitments to irreversible investments in internal development or acquisition. However, Reuer & Leiblein (2000) found that although firms did exhibit a real options pattern of investment in international expansion, this did not limit downside risk. Contrary to hypotheses, larger multinational portfolios (measured by the number

of countries entered), and smaller investments (indicated by the presence of joint ventures) contributed to below target performance outcomes (Reuer & Leiblein, 2000). These studies correspond to one of the three real options foundations - irreversibility. Additional investigations of real options have incorporated the principles of uncertainty and managerial flexibility, which I review next. Table 2.2 summarizes the empirical research corresponding to these three principles of real options theory.

Uncertainty

Decision making under uncertainty is the cornerstone of real options theory (Dixit & Pindyck, 1994; Amram & Kulatilaka, 1999). Uncertainty is reflected in the dynamism and complexity of the external environment (Aldrich 1979; Dess & Beard, 1984) and the ambiguity and complexity of the internal task environment (Duncan, 1972; Reus, Ranft, Lamont & Adams, 2009). In the context of innovation, the uncertainty associated with market timing, the combination of technical and demand uncertainty, is particularly relevant (Santos & Eisenhardt, 2009; Teece, 1986).

Technical uncertainty occurs in the external environment due to the array of competitors (complexity) vying for technical and market dominance in the industry and the pace (dynamism) at which it evolves (Utterback & Abernathy, 1975; Anderson & Zeithaml, 1984). Technical uncertainty outside the firm is resolved over time as firms acquire new information about the emergence of dominant technologies and competitors (Dixit & Pindyck, 1994; Reus et al., 2009). Thus external technical uncertainty incents firms to hold options while competitive dynamics are played out and new information is acquired (McGrath, 1997).

In contrast, technical uncertainty inside the firm is resolved through action and further investment (Galbraith, 1973; Thompson, 1967). For example, investments in research and

development, knowledge management systems and cross-functional knowledge transfer are instrumental in reducing internal technical uncertainty associated with innovation (Kogut & Zander, 1992; Reus et al., 2009). Therefore, in contrast to external sources of technical uncertainty, internal technical uncertainty creates urgency for firms to act (Dixit & Pindyck, 1994; Folta, 1998; McGrath, 1997).

Market uncertainty is a source of external uncertainty and is comprised of demand and competitive uncertainty (Folta, 1998; McGrath, 1997). Demand uncertainty stems from the unpredictability of the size and rate of growth in new product markets (Eisenhardt & Schoonhoven, 1996). Demand uncertainty creates an incentive for the firm to delay investment until more information emerges and uncertainty is diminished (Duncan, 1972; Reus et al., 2009). Yet the threat of competitive preemption poses a risk to delay (Dixit & Pindyck, 1994; Kulatilaka & Perotti, 1998). This tension between action and deferment, that is exercising or holding an option, is amplified in environments of high dynamism and complexity (Duncan, 1972; Folta & O'Brien, 2004). Thus, greater uncertainty increases the value of holding an option (Kogut & Kulatilaka, 2001; Reuer & Tong, 2005).

Bowman & Hurry (1993) proposed that firms which hold options in uncertain environments and exercise options as uncertainty is reduced will have superior growth and profit performance in the long term. To accomplish this, firms must be attuned to information that signals a change in the level of uncertainty. Opportunity arrival signals such as an increase in demand, adoption of a technology standard or opening of international markets signal reduced uncertainty and provide an impetus to take action and exercise the option. Opportunity expiration signals such as competitive preemption indicate the closure of an opportunity is imminent and the option would have little value if held beyond this point. Bowman & Hurry (1993) proposed

that options that are exercised in response to receiving both opportunity arrival and expiration signals will perform better than options exercised in response to only one signal or no information at all. Although empirical tests linking the holding or exercise of real options to firm performance are lack, several studies do provide evidence of the propensity to exercise options under conditions of uncertainty.

Kogut (1991) applied real options theory to the study of joint ventures, focusing on the propensity for firms to acquire or divest their position in the joint venture in response to resolution of market uncertainty. A joint venture represents creation of a real option because it is an initial investment in an uncertain opportunity that frequently contains the right but not the obligation to increase participation in the future through acquisition of the partner's interest. A joint venture also limits downside loss by sharing the investment and risk with one or more partners and allowing for divestment in the future (Kogut, 1991). The study found that positive market demand signals increased the propensity to acquire the partner's interest in the joint venture, supporting the idea that opportunity arrival signals encourage exercise of the options (Bowman & Hurry, 1993; Kogut, 1991). However negative market demand signals had no effect on divestment. Firms continued to hold options and delay further investment even in response to negative signals, suggesting the presence of option traps (Adner & Levinthal, 2004b; Kogut, 1991).

Further evidence that firms exercise options as uncertainty is reduced is provided by Folta & Miller (2002). This study of biotech firms found evidence to suggest that firms exercised options to acquire additional equity in technology partners in response to opportunity arrival signaled by an increase in the market value of the partner firm. Likewise, opportunity expiration signaled by an increased likelihood of competitive preemption triggered a similar response.

Table 2.2 Real Options Theory Empirical Studies

Authors/Journal	Topic/Sample	Variables and Measures	Major Findings
Irreversibility			
Hurry, Miller & Bowman, 1992, SMJ	Venture capital Survey of 20 Japanese and 20 US Venture capital firms and corporate venturing units	Comparison of Japanese and US venture capital investment patterns. IV: Frequency of categorical measures for size of investment, size of portfolio, time horizon, strategic objectives and monitoring.	Venture capital investment behavior of Japanese firms fits the pattern of real options with small investments followed by increasing stakes over time, large portfolios and long term interest.
Reuer & Leiblein, 2000	International joint ventures and subsidiary investments 357 manufacturing firms, Compustat, CRSP and Directory of Corporate Affiliations	DV: below target performance outcomes IV: number of countries, number of IJV's	Contrary to theory and hypotheses multinationality do not reduce downside risk. and IJV's increase downside risk
Uncertainty			
Kogut, 1991	Joint ventures Survey of 92 joint ventures	DV: propensity to acquire or divest. IV: Annual venture growth	A joint venture represents the option to expand. A favorable market demand signal increases the propensity to acquire (growth option). Negative signals have no effect on dissolution (option to delay).
Kim & Kogut, 1996	Platform technologies and market entry 176 semiconductor startups	DV: Entry in a new area IV: market growth, prior experience	Platform technologies create options on the future technological trajectory and market entry. Market entry timing coincides with growth markets in a new technological area.

Table 2.2 Continued

Authors/Journal	Topic/Sample	Variables and Measures	Major Findings
McGrath & Nerkar, 2004	R&D investment 31 pharmaceutical firms, 1979-1995: Cox proportional hazard	DV: Propensity to take out a growth option (second patent in a new area). IV: Scope of opportunity (number of technological classes and claims on the first patent); Cumulative investment (patent count); Effects of competition (number of competitors and patents per competitor in the new area).	The propensity to invest in a growth option in a new area is positively related to the scope of opportunity in that area. There is a negative relationship between the propensity to invest in a growth option in a new area and the extent of commitments and cumulative investments in prior areas. There is a positive relationship between the propensity to invest in a growth option in a new area and the level of competition in that area.
Reuer & Tong, 2005, JOM	International joint ventures SDC database IJV's 1995-2002. 2,594 IJV transactions	DV: explicit option to acquire equity in an IJV IV: core v. non-core SIC, intellectual property rights in host country, cultural distance, political turmoil,	An explicit option to acquire equity in an IJV is more likely under conditions of greater uncertainty. This is an example of a growth option.
Tong, Reuer & Peng, 2008	International joint ventures 293 firms, 2698 firm year observations 1989-2000. SDC, Stern Stewart, Compustat	DV: growth option value IV: number of IJV's, minority stake, core v. noncore.	Minority IJV's and diversifying IJV's contribute to growth option value but other types do not.
Oriani & Sobrero, 2008 SMJ	R&D investment 290 UK manufacturing firms	DV: market value of R&D investment IV: market uncertainty, technical uncertainty M: munificence	Market uncertainty has a U shaped relationship with market value of R&D investment, matter of growth. Technical uncertainty has an inverted U shaped relationship with market value of R&D, matter of survival.

Table 2.2 Continued

Authors/Journal	Topic/Sample	Variables and Measures	Major Findings
Managerial Flexibility			
Folta, 1998	Governance 402 transactions in biotech	DV: propensity to take an equity stake, form a JV or acquire. IV: technological distance, growth potential, exogenous technical uncertainty, threat of preemption	Propensity for joint ventures and equity stakes over internal investment or acquisition of new technologies in environments of high exogenous technological uncertainty.
Folta & Miller, 2002	Equity stake in technology partner	DV:	Resolution of uncertainty and threat of competitive preemption increased the propensity to buy out the joint venture partner (exercise the option).
Folta & O'Brien, 2004	Market entry Compustat	DV: market entry IV: uncertainty M: irreversibility, value of growth opportunity, early mover advantage	The tension between option to defer and option to grow in the presence of uncertainty. Nonmonotonic relationship. Uncertainty decreases propensity to enter until threshold is reached and higher levels increase propensity to enter.

Similarly, McGrath & Nerkar (2004) found that pharmaceutical firms were more likely to invest in growth options in a new area when the scope of opportunity was large (opportunity arrival signal) and competitive preemption was considered likely (opportunity expiration signal).

Subsequent studies of international joint ventures provide support for the proposition that greater uncertainty increases the value of holding an option. Reuer & Tong (2005) found that higher uncertainty in external host country conditions and internal technical experience increased the likelihood that international joint venture agreements would contain an explicit option to acquire equity in the future. Similarly, Tong, Reuer & Peng (2008) found that conditions of greater uncertainty, specifically joint ventures with minority stakes or that are outside the firm's core business, increased the option value of the firm. Conversely, conditions of less uncertainty such as majority stakes or core business joint ventures did not increase the option value of the firm.

Oriani & Sobrero (2008) investigated the market value of the firm's R&D investment under conditions of technical and market uncertainty. They found evidence consistent with theory that greater market uncertainty increases the value of the option to delay further investment. However, this relationship reached an inflection point beyond which increasing uncertainty decreased the value of the option to delay and increased the value the growth option created by incremental investment in R&D. This U-shaped relationship suggests that when market growth potential is very high growth options have more value than options to delay. Conversely, greater technical uncertainty increased the value of growth and flexibility options initially, but again reached an inflection point beyond which the value of these options declined. This inverted U relationship suggests that when technical uncertainty is very high, the option to delay has higher value than growth and flexibility options. Overall, these findings support theory

on the tensions between the option to delay investment and the incremental investment in growth or flexibility options.

These findings are consistent with earlier studies of uncertainty and market entry decisions. Folta & O'Brien (2004) found evidence of a non-monotonic relationship such that uncertainty decreases the propensity to enter new markets (option to delay) until a threshold is reached; then higher levels increase the propensity to enter new markets (growth option).

The third type of uncertainty, and perhaps of most interest to strategic management scholars, is that segment of external uncertainty that firms can influence through strategic action (Amit & Schoemaker, 1993; Hamel & Prahalad, 1994; Teece, Pisano & Shuen, 1997). Real options investments have been characterized as strategic actions aimed at influencing external uncertainty idiosyncratically in favor of the firm, without benefitting all firms (McGrath, 1997; Kulatilaka & Perotti, 1998). Options investments in technological innovations move firms up the experience curve ahead of competitors, reducing internal uncertainty (Kogut & Kulatilaka, 2001). These investments also influence the technological platform in the industry to move in the direction of the firm's technology, reducing external uncertainty in its favor (Kim & Kogut, 1996). This secures an advantageous industry position for the firm; while firms without prior experience will be at a disadvantage, as will those that committed fully to investments that are not aligned with the emergent industry technology (Kulatilaka & Perotti, 1998;). Thus, investments in technological innovations using a real options approach influence the competitive environment in favor of the innovating firm (Kogut & Kulatilaka, 2001; McGrath, 1997). Jacobides et al., 2006) along with Pisano & Teece (2007) propose that firms may influence industry architectures in their favor through proactive engagement of potential partners and

rivals. Some of this engagement is likely to be in the form of deliberate external commercialization through other firms (Chesbrough, 2003; Pisano & Teece, 2007).

To summarize, internal uncertainty is reduced through learning and experience (Kogut & Zander, 1992; Reus et al., 2009), and external uncertainty is resolved as market and competitive scenarios are revealed through new information (Reus et al., 2009; Eisenhardt & Schoonhoven, 1996). In addition options investments in capabilities may influence the resolution of uncertainty in the firm's favor, which positions the firm to exploit the opportunity advantageously relative to industry competitors (Kim & Kogut, 1996; Jacobides et al., 2006). Thus, from a real options perspective uncertainty is construed as an opportunity (Kogut, 1991; Kim & Kogut, 1996) rather than a threat (Cyert & March, 1963). Optimal exploitation of these opportunities depends on the third tenet of real options theory, managerial flexibility.

Managerial Flexibility

Managerial flexibility to adapt strategic investment decisions in a contingent fashion is the third principle of option value (Dixit & Pindyck, 1994). Managerial flexibility captures the intuitive appeal of 'keeping your options open' in uncertain environments (Bowman & Hurry, 1993). "In sum, real options are investments that can be characterized as sequential, irreversible investments made under conditions of uncertainty. The options create value by generating future decision right and, in this way, providing strategic flexibility. This flexibility is more valuable the higher the level of uncertainty" (Vanhaverbeke et al., 2008). This flexibility is expressed in different option decisions which include hold, exercise or abandonment (Copeland & Antikarov, 2001; Amram & Kulatilaka, 1999).

Hold. Managers may hold the option created by the initial investment until more information is known and uncertainty is reduced. For example, minority stakes in joint ventures

can be held until favorable demand signals trigger managers to exercise the option and increase the equity stake in the joint venture (Folta, 1998; Folta & Miller, 2002; Folta & O'Brien, 2004). However, holding the option is valuable only if the forthcoming information is worth more than the risk of competitive pre-emption (Trigeorgis, 1996). Holding an option is often referred to as a timing option or an option to delay (Amram & Kulatilaka, 1999).

Exercise. Options are exercised when opportunity arrival or expiration signals prompt managers to act (Bowman & Hurry, 1993). Options are fully exercised when full investments are made to complete the project, such as acquisition of a joint venture partner or commercialization of a new product. Alternatively, when options are exercised incrementally a series of nested options are created and this sequence is followed until the project is completed or abandoned.

Abandonment. Abandonment refers to the decision to stop investment and cancel the project (Amram & Kulatilaka, 1999; Dixit & Pindyck, 1994). If the project changes form and continues, this is considered a nested option, rather than abandonment (Bowman & Hurry, 1993; McGrath et al., 2004). Recalling that the premise of options is to limit downside risk while enhancing upside potential, the option to halt investment and abandon the project must be available (Adner & Levinthal, 2004a). "It is precisely the choice of walking away from a venture that gives meaning to the term 'option', incidentally" (Hurry et al., 1992: p. 97). A good deal of debate surrounding the abandonment option and the risk of option traps continues in the literature (Adner & Levinthal, 2004a; Adner & Levinthal, 2004b; McGrath et al., 2004).

An option trap describes managers propensity to continue rather than abandon projects (Adner & Levinthal, 2004a). Options traps are facilitated by the fact that real options do not have an expiration date and can be held or nested indefinitely (Dixit & Pindyck, 1994). Adner & Levinthal (2004) argue that real options must include ex-ante criteria for project abandonment to

meet the options assumption of limits on downside risk. When real options are applied without abandonment criteria managers are caught in option traps that facilitate their tendency to continue projects, rather than cancel them (Barnett, 2008; Coff & Laverty, 2001). In the option trap scenario managers avoid cancellation of projects that might be successful in the future. However, this means continuing projects that may be unsuccessful and is likely to result in overinvestment (Adner & Levinthal, 2004b). This is a type I error, equivalent to accepting an incorrect hypothesis. Conversely, evaluation processes that emphasize risk reduction to avoid type I errors, may result in underinvestment and missed opportunities. This is a type II error, equivalent to rejecting a correct hypothesis (Chesbrough, 2003; Coff & Laverty, 2001). This tradeoff, depicted in Table 2.3, is at least partly imposed by the boundaries of the firm.

Table 2.3 Errors in Internal Commercialization of Innovations

	Abandon	**Commercialize**
Innovation would be successful	**Type II error** Incorrectly abandon an otherwise successful innovation	Correctly commercialize a successful innovation
Innovation would be unsuccessful	Correctly abandon an unsuccessful innovation	**Type I error** Incorrectly commercialize an unsuccessful innovation

Consider the option to commercialize an innovation. When evaluated within the boundaries of the firm the decision alternatives are to hold, exercise or abandon. Holding the option means delaying commercialization but keep the project alive. This is the scenario that leads to potential option traps of continuing projects indefinitely in the absence of abandonment criteria (Adner & Levinthal, 2004a). Exercising the option involves a full investment in

commercialization of the innovation (and risk of type I error). Abandonment halts investment in the innovation, realizing full sunk costs (and risk of type II error). However, options for external commercialization (outside the boundaries of the firm) have potential to mitigate the tradeoffs inherent in closed (internal) innovation approaches (Chesbrough, 2003). An option to license a patent or process to an outside firm strikes a balance between in avoiding both type I and type II errors. For example, licensing a technology to an outside firm enables the firm to both save the full cost of commercialization and recoup some of the investment through licensing fees (Fosfuri, 2006).

In sum, this section provided a review of real options theory framed by the core tenets of irreversibility, uncertainty and managerial flexibility. Table 2.2 summarizes the empirical literature on real options theory. The section concluded with the risks of real options traps and the tradeoffs associated with innovation commercialization decisions. I suggested that external commercialization may mitigate this compromise. In the next section I introduce external commercialization, framing it as a real option on the underlying investment in innovation.

External Commercialization

External commercialization introduces a broader set of alternatives for exercising the option to commercialize an innovation. For example, the firm may commercialize an innovation outside the firm through mechanisms such as outlicensing, sale of intellectual property rights, corporate venturing, or spin offs (Arora, Fosfuri & Gambardella, 2004; Grindley & Teece, 1997). External commercialization enables exercise of the innovation option without full investment in commercialization (McGrath, 1997). It also allows the firm to realize revenue and recoup R&D investment on innovations that might otherwise not be commercialized within the firm (Chesbrough, 2003; Rivette & Kline, 2000).

Thus, considering external commercialization options increases the option value on innovation by increasing the upside potential while limiting downside risk and decreasing the chance of error (Kogut & Kulatilaka, 2001). Specifically, it activates an additional range of outcomes, increasing the variance of outcomes on the upside and therefore the value of the option (McGrath, 1997; Myers, 1977). Further, it capitalizes on the advantages of a sequence of nested options that are enacted/emergent over time as both endogenous and exogenous uncertainties are reduced (Kim & Kogut, 1996). Finally, it relaxes constraints on the idiosyncratic value of the option to the focal firm by considering commercialization avenues outside firm boundaries (Teece et al., 1997; Vanhaverbeke et al., 2008). However, further guidance is needed to understand what conditions prompt a firm to exercise an external commercialization option. The logic to address these questions of external commercialization and implications for firm performance is provided by the appropriability framework (Teece, 1986) which I discuss in the next section.

Appropriability Framework

> *"In reality, however, an innovation at its early stages – consisting perhaps of an invention plus some ideas about its application – presents a rich variety of potentials, a set of options that might be pursued in diverse ways. This range of meaning for what the innovation is, has much to do with the range of appropriability strategies available to the innovator"* (Winter, 2006: p. 1104).

Teece (1986) introduced the appropriability framework in his seminal work on *Profiting from Innovation*. Appropriability refers to how value generated by the innovation is distributed among the innovating firm and other entities in the industry such as rivals, imitators, suppliers or customers (Ceccagnoli, 2009; Teece, 1986; Winter, 2006). The appropriability framework (Teece, 1986) identifies conditions which influence the extent to which the innovating firm will

appropriate value from its own innovation. The framework proposed that innovating firms would appropriate value based on: 1) the degree of control over complementary assets, 2) the strength of the appropriability regime (the extent of IP protection), and 3) market timing (environmental uncertainty).

Complementary assets are the processes, resources, and related products and services necessary to commercialize the focal innovation (Teece, 1986). Complementary assets may be controlled by the innovating firm or by other firms including rivals, suppliers, customers or providers of related products and services (Tripsas, 1997). The extent of the firm's control over complementary assets determines the value that the innovating firm will appropriate relative to other firms, with greater control resulting in higher appropriation for the innovating firm (Teece, 1986).

Table 2.4 Predictions from the Appropriability Framework

Appropriability Dimensions	**High Appropriation by the Innovating Firm**	**Low Appropriation by the Innovating Firm**
Degree of control over complementary assets	High control over complementary assets	Low control over complementary assets
Strength of appropriability regime	Strong appropriability regime	Weak appropriability regime
Market timing/ level of uncertainty	Low uncertainty associated with market timing	High uncertainty associated with market timing

The appropriability regime is "the protection afforded the innovator by intellectual property protection and natural barriers to imitation" (Pisano & Teece, 2007: p. 279). The strength of the appropriability regime influences the value that the innovating firm will appropriate relative to other firms, with stronger appropriability regimes favoring higher appropriation by the innovating firm (Cohen et al., 2000; Teece, 1986).

The market timing component of the appropriability framework captures the influence of environmental uncertainty on appropriability (Teece, 1986). For example the emergence of a dominant design or technology in the product market (Utterback & Abernathy, 1975), the size and growth of market demand and competitive rivalry are all uncertainties that influence the innovating firm's ability to appropriate value from its own innovation (Pisano & Teece, 2007). The dimensions of the appropriability framework and the general prediction for appropriation by the innovating firm are summarized in Table 2.4

Summary

This chapter began with a review of real options theory. The key tenets of irreversibility, uncertainty and managerial flexibility undergird the premise of real option value; namely, the ability to increase potential gain while limiting downside loss. Real options are created by an initial investment in a project that provides the firm preferential access to opportunity in the future. Once created, managers have the flexibility to hold, exercise or abandon the option. Real options apply to investments in innovation which occur in environments of uncertainty. Because not all outcomes can be predicted ex-ante, incremental investments in innovation yield a series of nested options.

Next, I illustrated how introducing the option to commercialize the innovation externally had a twofold effect: first, increasing the value of the option by increasing the number of alternatives for profiting from the innovation, second, reducing the hazards of option traps by introducing commercialization options outside firm boundaries. Finally, I introduced the appropriability framework. Appropriability conditions of complementary assets, appropriability regime (intellectual property protection) and market timing/uncertainty influence the firm's ability to profit from innovation.

In the next section I map the appropriability framework (complementary assets, appropriability regime and market timing) onto the tenets of real options theory (irreversibility, uncertainty and managerial flexibility) to develop the theoretical model which informs the two research questions in this dissertation. *1. What conditions influence the extent to which a firm engages in external commercialization? 2. To what extent does external commercialization influence firm performance?*

Theoretical Model

The foundation for the theoretical model is real options theory. Real options theory provides a heuristic for decision making under uncertainty. In the literature review I identified three tenets of real options theory: irreversibility of investment, uncertainty and managerial flexibility (Dixit & Pindyck, 1994). Irreversibility of investment and uncertainty are further delimited by the constructs introduced in the appropriability framework; specifically complementary assets, appropriability regime and market timing (Teece, 1986). The relationship between the tenets of real options theory and the dimensions of the appropriability framework are highlighted in Table 2.5

The model is based on an assumption that the investment in innovation is an irreversible investment in an underlying asset which the firm has the option to invest in further and ultimately commercialize at some time in the future (McGrath, 1997; Miller, 2002).Whether the asset is in the form of a patent, trade secret or tacit know-how, it constitutes valuable intellectual property that the firm can potentially profit from (Teece, 1986). Firms that allocate resources to research and development capability accumulate a stock of intellectual property assets and are motivated to earn a return on this investment. Commercialization of the innovation earns a return on the investment in innovation and contributes to overall firm performance (Hamel, 2000;

Rosenbusch et al., 2011). The extent of the contribution to firm performance is further influenced by the dimensions of the appropriability framework (Teece, 1986).

From a real options perspective an investment in complementary assets is also an irreversible investment made by the innovating firm. Successful commercialization of the focal innovation often requires complementary assets which the firm may or may not already own (Teece, 1986; Tripsas, 1997). For example, investment in a chemical plant may be required to produce and commercialize a patented compound on a large scale (Fosfuri, 2006). The appropriability framework predicts that the firms control over complementary assets influences the extent to which it is likely to appropriate value from its own innovation such that low control over complementary assets diminishes the level of appropriability (Teece, 1986).

The dimensions of uncertainty in this real options model are also provided by the appropriability framework; specifically the appropriability regime and market timing. The appropriability regime is the strength of intellectual property protection or barriers to imitation available to the innovating firm (Pisano & Teece, 2007). Although formal intellectual property protection laws are present, limitations and loopholes in rules and enforcements introduce uncertainty regarding whether the innovating firm will be able to protect its innovation (Cohen et al., 2000). The appropriability framework proposes a direct relationship between the appropriability regime (strength of intellectual property protection) and the ability of the innovating firm to appropriate profits from the innovation. Overall, a weak appropriability regime enables competitors to imitate and appropriate a relatively large share of profits away from the innovating firm.

The market timing dimension of the appropriability framework captures how environmental uncertainty influences whether or not firms are likely to appropriate profits from

innovation (Teece, 1986). For example the emergence of a dominant technology in the product market, the size and growth of demand and competitive rivalry are all external uncertainties that influence the timing with which the firm may exercise their option (Pisano & Teece, 2007). Firms holding an option on valuable intellectual property may adjust the timing of the exercise, trading off the benefit of uncertainty reduction with the risk of competitive preemption (Bowman & Hurry, 1993; Jacobides et al., 2006). The appropriability framework demonstrates how the uncertainty captured by market timing influences the level of appropriation garnered by the innovating firm. Broadly speaking, higher levels of uncertainty imply lower levels of appropriation for the innovating firm.

While the appropriability framework makes general predictions about the share of value that will accrue to the innovating firm, it also suggest that managers may influence the level of appropriability by selecting contingent strategies. Therefore managerial flexibility, the third tenet of real options theory, is proposed as an intervening variable in the model.

Table 2.5 Mapping the Appropriability Framework to Real Options Theory

Real Options Theory	Irreversibility	Uncertainty	Managerial flexibility
Appropriability Framework	• Innovation • Complementary assets	• Market timing • Appropriability regime	• Commercialization strategy

Managerial flexibility is expressed in the manager's selection of commercialization strategy. Managers have flexibility to choose from internal and/or external commercialization options (Vanhaverbeke et al., 2008).

The theoretical model is shown in Figure 2.1. The choice of commercialization strategy will be influenced by the appropriability conditions; specifically, irreversible investment in

complementary assets and the uncertainty associated with the appropriability regime and market timing. Accordingly, managers will select a commercialization strategy that enhances the level of appropriation for the innovating firm (Jacobides et al., 2006; Pisano & Teece, 2007). Therefore the commercialization strategy mediates the appropriability conditions impact on firm performance. This model depicts the commercialization strategy as a mediator of the relationship between appropriability conditions and firm performance in an integrated model of real options theory and the appropriability framework. The hypotheses in the next section explicate each of the appropriability conditions and demonstrate how the choice of commercialization strategy under these conditions influences firm performance.

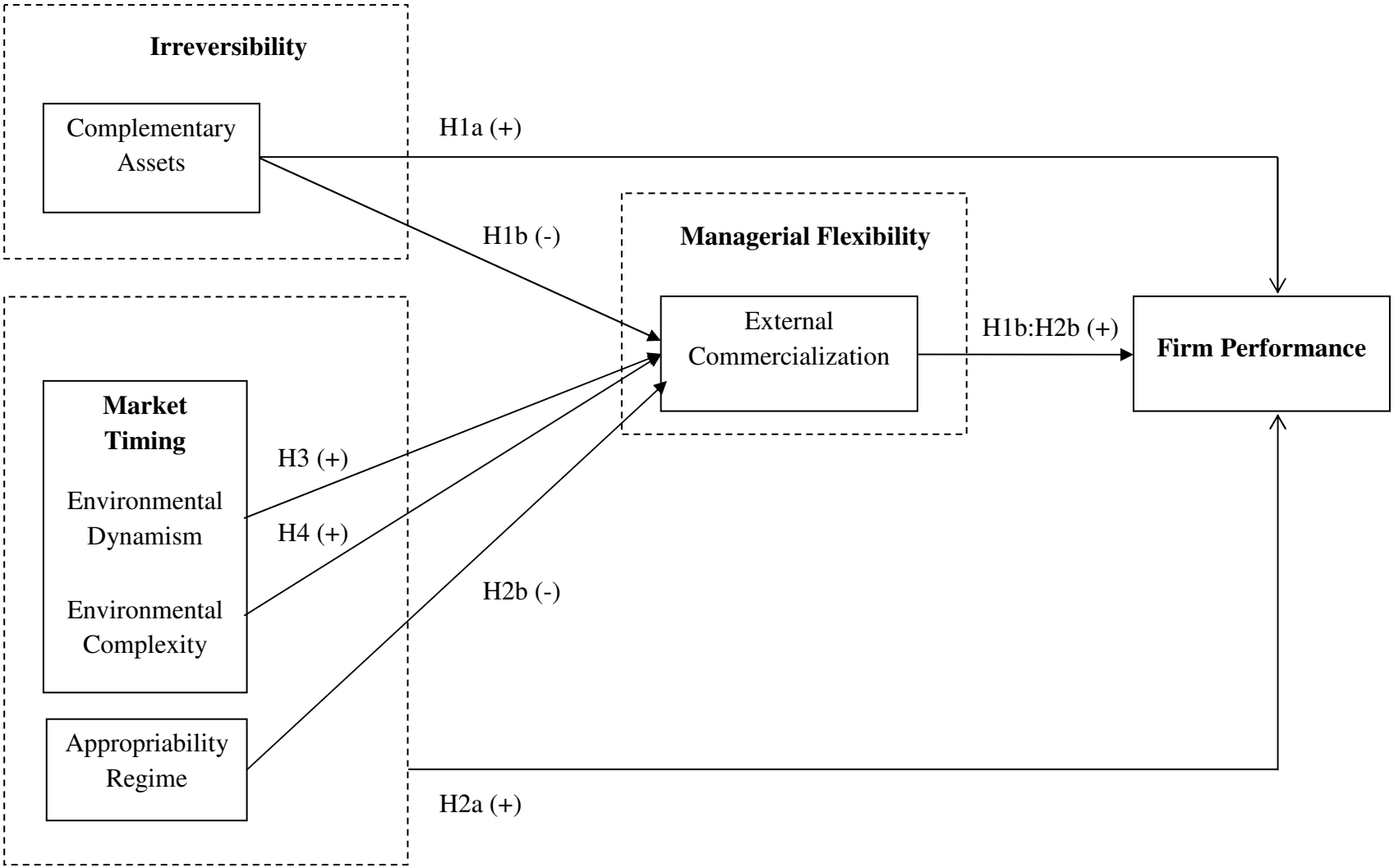

Figure 2.1 Real Options and External Commercialization

Hypotheses Development

In this section I hypothesize that each of the dimensions of the appropriability framework, complementary assets, appropriability regime, and market timing/uncertainty, influences the selection of a contingent commercialization strategy and firm performance. Specifically, an external commercialization strategy mediates the relationship between the appropriability conditions and firm performance. These relationships are depicted in Figure 2.1 and the logic is provided under each sub-heading in this section.

Complementary Assets

Complementary assets is one dimension of the appropriability framework (Teece, 1986). Innovations rarely stand alone; more often than not, they must be accompanied by complementary assets to capture value. Drawing from Teece (1986; 2006), I define complementary assets as the processes, resources, and related products and services necessary to commercialize the focal innovation. Complementary assets may be controlled by the innovating firm or by other firms including rivals, suppliers, customers or providers of related products and services. The extent of the firm's control over complementary assets determines the value that the innovating firm will appropriate relative to other firms.

However, it is unlikely that the innovating firm will control all of the complementary assets it needs (Adner & Kapoor, 2010). If the needed complementary assets are generic, i.e., multi-purpose and widely available in the market, the innovating firm can retain a high degree of control and stay well-positioned to appropriate value from the innovation. In contrast, specialized complementary assets have high value with respect to the innovation but relatively low value outside this complementary role. Therefore investments in specialized complementary assets involve higher risk because of the dependence on the focal innovation (Teece, 1986).

Additionally, innovating firms often lack the knowledge or resources to develop or acquire specialized complementary assets, or cannot do so with sufficient urgency (McGrath, 1997; Pisano & Teece, 2007) and must therefore rely on other firms to provide specialized complementary assets. By doing so, the innovating firm must relinquish a degree of control, and some share of the profits, from the innovation (Adner & Kapoor, 2010). As an extreme case of specialized complementary assets are bottleneck assets. These are necessary, non-substitutable, and in limited supply (Teece, 1986), which means the provider of the bottleneck assets has a high degree of control over those assets (Pisano & Teece, 2007). Moreover, an innovating firm that needs access to the bottleneck assets must share a portion of their innovation's value with the firm that controls the bottleneck assets (Pisano & Teece, 2007). Thus, the firm's control over complementary assets and consequent share of appropriability depends on the specialization as well as the ownership of the complementary asset.

The link between complementary assets and appropriability is supported by evidence that complementary assets are more effective in appropriating value from innovation than is patent protection (Cohen et al., 2000). Accordingly, innovating firms with less control over complementary assets are challenged to seek alternative strategies for appropriating value from the innovation (Arora & Ceccagnoli, 2006). External commercialization strategies may benefit innovating firms with limited control over complementary assets that still hope to preserve appropriation from innovation. Indeed, research confirms that firms with less control over complementary assets have a higher propensity to license innovations (Arora & Ceccagnoli, 2006).

Through a deliberate external commercialization strategy, innovating firms can benefit from leveraging another firm's superior position in complementary assets in at least three ways

(Chesbrough, 2003). First, the presence of the complementary assets expands the market for the innovation, creating more value to be distributed among the innovating firm as well as the firms providing complementary assets (Jacobides et al., 2006). Second, proactively linking the focal innovation to the complementary assets of other firms allows those firms to appropriate value from the innovation, discouraging potential imitation (Teece & Pisano, 2007). Finally, leveraging other firms' complementary assets enables the innovating firm to allocate scarce resources to the focal innovation while sharing the risk of investment in complementary assets with other firms (Adner & Kapoor, 2010). Thus, innovating firms that exploit the complementary assets of other firms through external commercialization strategies are likely to increase their share of profits from innovation and enhance firm performance. Therefore I hypothesize:

> *Hypothesis 1a: There is a positive relationship between complementary assets and firm performance.*
>
> *Hypothesis 1b: The commercialization decision mediates the positive relationship between complementary assets and firm performance. Specifically, less control over complementary assets will lead to increased levels of external commercialization and subsequent increased firm performance.*

Appropriability Regime

Following complementary assets, the appropriability is a second dimension of the appropriability framework (Teece, 1986). The appropriability regime is defined as "the protection afforded the innovator by intellectual property protection and natural barriers to imitation" (Pisano & Teece, 2007: p. 279). The strength of the appropriability regime in an industry is determined by the industry participants' use of patents, trade secrets, and natural barriers to imitation to protect their innovations (Levin et al., 1987; Cohen et al., 2000). Appropriability regimes vary widely across industries and range from tight, in which innovators

enjoy a high degree of protection, to weak, in which innovators experience lower levels of protection (Teece, 1986).

Tight appropriability regimes offer high levels of protection for innovators through the use of patents, trade secrets, and natural barriers to imitation. Firms in industries with tight appropriability regimes have high rates of patenting and protect their innovations with aggressive patenting strategies (Cohen et al., 2000). For example, firms may use a patent blocking strategy by securing patents for their innovations as well as any related and substitute technologies, effectively creating a patent fence around the area of the innovation to preempt imitation by competitors (Cohen et al., 2000). Cross-licensing agreements that provide reciprocal access to technology among industry participants, who are often competitors, also motivate aggressive patenting in an industry because firms need strong patent stocks to increase their bargaining power in cross-licensing negotiations and disputes (Grindley & Teece, 1997).

When legal patent protections are not necessary or obtainable (Cohen et al., 2000), firms in industries with tight appropriability regimes can also use trade secrets and natural barriers to imitation to protect their innovations. Trade secrets are effective in protecting products such as chemical compounds or recipes that are difficult to imitate or reverse engineer after they are released in the market; thus, trade secrets are preferred over patents when the amount of information disclosed in the patent facilitates rather than prevents imitation (Cohen et al., 2000). Alternatively, natural barriers to imitation are inherent in the innovation itself; for example, process innovations tend to be inimitable because they are tightly linked to other firm capabilities and are not readily observable (Abernathy & Utterback, 1978; Ettlie & Reza, 1992). The protections offered by patents, trade secrets, and natural barriers to imitation in tight

appropriability regimes allow firms a high level of appropriation of profits from innovation and subsequent contribution to firm performance (Teece, 1986).

In contrast, weak appropriability regimes offer less protection from patents, trade secrets, and natural barriers to imitation (Nelson, 2006). Several conditions contribute to deficiencies in intellectual property protection. Lack of novelty is one reason that patents are either not sought or denied. When granted, the patent often covers a narrow area leaving room for imitators to invent around the scope of protection (Cohen et al., 2000). The expense of application, maintenance and enforcement of patents is another barrier to full patent protection, particularly for firms with limited resources (Gans & Stern, 2010). Additionally, trade secrets are not effective for products that can be easily reverse-engineered and many products do not have the inimitable characteristics common to process innovations (Leiponen & Byrma, 2009). Thus, innovating firms operating in environments with weak appropriability regimes have few protections available to them and often experience rapid imitation through which rivals may quickly appropriate profits (Teece, 1986). Thus innovating firms operating in weak appropriability regimes are less likely to accrue performance benefits from innovation than those in tight appropriability regimes.

Innovating firms that enjoy the protection afforded by tight appropriability regimes are able to appropriate profits from innovation through traditional vertically integrated commercialization. Indeed, firms using patent blocking strategies typical under conditions of tight appropriability regimes were found to be less likely to license their intellectual property (Motohashi, 2008). However, firms operating in weak appropriability regimes cannot rely on intellectual property protection to appropriate profit from innovation. Innovators challenged by

weak appropriability regimes may increase their profits from innovation by pursuing an external commercialization strategy (Chesbrough, 2003).

External commercialization allows the innovator to appropriate value in several ways. First, the innovator receives direct licensing revenue. Second, more market participants helps stimulate demand for the innovation, expanding the rate of growth and size of the market. Third, providing access to the technology through deliberate licensing pre-empts accidental spillover and deters competitive imitation. In effect, the external commercialization strategy enables the innovating firm to secure a position in the industry that allows continued appropriation of a portion of the profit from innovation while facilitating appropriation by others. Under conditions of a weak appropriability regime, an external commercialization strategy enables appropriation of profit from innovation which contributes to enhanced firm performance. Therefore I hypothesize:

> *Hypothesis 2a: There is a positive relationship between appropriability regime and firm performance.*
>
> *Hypothesis 2b: The commercialization decision mediates the positive relationship between the appropriability regime and firm performance. Specifically, a weaker appropriability regime will lead to increased levels of external commercialization and subsequent increased firm performance.*

Market Timing

Market timing is the third appropriability condition in the framework (Teece, 1986) and manifests the uncertainty underlying real options theory (Bowman & Hurry, 1983; McGrath, 1997). Market timing includes the presence or absence of a dominant technology or design (Utterback & Abernathy, 1975), the size and growth of the market (Eisenhardt & Schoonhoven, 1996) and competitive rivalry (Derfus, Maggitti, Grimm & Smith, 2008; Porter, 1985). The degree to which the innovating firm can potentially profit from innovation is influenced by these

sources of environmental uncertainty (Teece 1986). Environmental uncertainty refers to "the extent to which future states of the environment can be anticipated or accurately predicted" (Tushman & Anderson, 1986: p. 445). Two dimensions of environmental uncertainty that are relevant to innovation are environmental dynamism and environmental complexity (Dess & Beard, 1984; Duncan, 1972; Eisenhardt & Schoonhoven, 1996).

Environmental dynamism. Environmental dynamism is defined as the relative stability versus instability in the industry and is often described as turbulence (Aldrich, 1979; Dess & Beard, 1984). Dynamism refers to unpredictability in the rate and magnitude of change in the external environment (Duncan, 1972; Reus et al., 2009).

Environments high in dynamism are those in which "changes in demand, competition, and technology are rapid and discontinuous" (Eisenhardt, 1989: p. 544). Technology changes are characteristic of new/product markets, industry and technological convergence and disruptive innovations (Thompson, 1967; Tushman & Anderson, 1986). The early stages of technological innovation involve a good deal of experimentation and trial and error by industry participants prior to the emergence of a dominant design (Teece, 1986; Utterback & Abernathy, 1975). High rates of industry entry and exit during this period make changes in the competitive structure unpredictable (Anderson & Zeithaml, 1984). Accordingly, the size and timing of demand, demand preferences and demand shifts between rivals are also unpredictable (Eisenhardt & Schoonhoven, 1996; Tushman & Anderson, 1986). Dynamism is typically higher in the early stages of product/market development before settling down through technical effort and the passage of time (McGrath, 1997; Miller & Friesen, 1984). Conversely, environmental dynamism is generally lower in later stages of the product/market life cycle. A dominant design has emerged and technological innovations evolve around this dominant design (Teece, 1986;

Utterback & Abernathy, 1975). Industry architectures are well defined and market shares are relatively stable (Anderson & Zeithaml, 1984). Likewise, demand growth and preferences are more predictable (Eisenhardt & Schoonhoven, 1996).

Recent evidence from the competitive dynamics literature shows that environmental dynamism, as well as complexity, contributes to volatility in firm performance (D'Aveni et al., 2010; Thomas & D'Aveni, 2009). As dynamism increases industry leaders enjoy shorter periods of superior performance and fall more frequently from their top positions (Derfus et al., 2008; Wiggins & Ruefli, 2005). Studies suggest that dynamism, complexity and volatility in performance have increased and spread across industries over time (Thomas & D'Aveni, 2009; Wiggins & Ruefli, 2002). In these environments a repertoire of innovation strategies, like other competitive moves, are critical to firm performance (Chesbrough et al., 2006; Chen, Katila, McDonald & Eisenhardt, 2010; Miller & Chen, 1996). Indeed, firms in dynamic environments have been shown to create more options for innovation through R&D investments (Chen et al., 2010). By extension, firms are also likely to expand their options for commercialization of innovation through external commercialization strategies.

Dynamic environments offer a unique opportunity for innovating firms to shape the emerging technical and competitive dynamics of the industry in their favor (Santos & Eisenhardt, 2009). External commercialization is one mechanism to achieve this (Jacobides et al., 2006; Pisano & Teece, 2007). Indeed, scholars propose that environmental dynamism increases the rate of inter-firm cooperation (Rosenkopf & Schilling, 2007). Findings confirm that innovating firms operating in turbulent industries are more likely to engage in deliberate external commercialization (Eisenhardt & Schoonhoven, 1996). Likewise, technical uncertainty stimulates demand for these innovations among industry participants (Arora & Gambardella,

2010a; Rothaermel & Alexandre, 2009; Rothaermel, Hitt & Jobe, 2006). Conversely, innovating firms in stable environments have less opportunity to influence technological, competitive and demand factors that are well established (Eisenhardt & Schoonhoven, 1996). Similarly, firms that dominate these stable industries have little incentive to proactively pull potentially disruptive innovations and new entrants into the mainstream of the industry (Christensen, 1997; Tushman & Anderson, 1986). Therefore innovating firms are more likely to pursue external commercialization strategies in turbulent rather than in stable environments.

External commercialization strategies enable innovating firms in turbulent environments to influence the dominant technical design and architecture of the industry (Eisenhardt & Schoonhoven, 1996; McGrath, 1997; Jacobides et al., 2006; Teece, 1986; Tushman & Anderson, 1986). Innovating firms that make their innovation available to industry participants through an external commercialization strategy stimulate further development around their technology platform and thus increase the likelihood that the firm's technology will emerge as the dominant design (Kogut & Kulatilaka, 2001; McGrath, 1997; Jacobides et al., 2006). In turn a broad base of support from industry participants may drive adoption of the innovating firm's technology in specifications of industry standards (Chesbrough, 2003; Teece, 2006). Access to the innovating firm's technology, granted through external commercialization agreements, will influence the extent to which industry participants choose to compete and/or occupy a position in the innovation value chain (Jacobides et al., 2006). Thus, the external commercialization strategy enables the innovating firm to secure a central position in the dominant design and industry architecture (Chesbrough, 2007; Pisano & Teece, 2007). Therefore I hypothesize:

> *Hypothesis 3: There is a positive relationship between environmental dynamism and external commercialization.*

Environmental complexity. Another component of environmental uncertainty is complexity. Environmental complexity refers to the number, similarity and relatedness of the environmental elements affecting the firm (Dess & Beard, 1984; Duncan, 1972). One of the most important elements of a firm's environment is other firms (Lawless & Anderson, 1996). For example, industry concentration takes into account the number of competitors, distribution of size and market share, and the range of product/market segments in the industry (Keats & Hitt, 1988; Porter, 1980).

Less complex environments have higher industry concentration, with few firms holding a large share of the market in a well defined industry (Keats & Hitt, 1988; Eisenhardt & Schoonhoven, 1996). The industry structure is well established and dominated by powerful firms that impose order on competitive rivalry across the industry (Porter, 1980). Therefore less complex industries have lower uncertainty (Dess & Beard, 1984). In contrast, more complex environments have lower industry concentration, with numerous well balanced rivals competing vigorously for market share (Porter, 1980). The scope of the industry tends to be diverse and segmented, and the boundaries of the industry are more fluid (Eisenhardt & Schoonhoven, 1996; Lawless & Anderson, 1996; Porter, 1980). Thus there is higher uncertainty in these industries (Dess & Beard, 1984).

Environmental complexity, similar to dynamism discussed in Hypothesis 3, increases the volatility of firm performance (D'Aveni, 1994; Thomas & D'Aveni, 2009; Wiggins & Ruefli, 2005). Likewise a broader repertoire of innovation strategies is required to sustain performance in these environments (Miller & Chen, 1996; Chen et al., 2010). Thus, the level of environmental complexity influences the propensity for firms to pursue external innovation strategies (Eisenhardt & Schoonhoven, 1996; Li & Atuahene-Gima, 2002; Powell, 1990).

External commercialization strategies in less complex environments are likely to be shaped by the structure of the industry with firms on the periphery seeking agreements with industry leaders (Ahuja, 2000; Powell, Koput & Smith-Doerr, 1996). However, industry leaders may have little incentive to cooperate with other firms that do not offer advantages that the leading firm does not already control. If agreements are made, for example in the case of access to a novel technology, the leading firm is likely to leverage superior bargaining power to secure favorable terms (Ahuja, 2000; Powell et al., 1996). Evidence confirms that less complex environments with less uncertainty have fewer inter-firm agreements for innovation (Eisenhardt & Schoonhoven, 1996; Shan, 1990). In these industries the agreements follow a hub and spoke pattern with large firms at the center (Rosenkopf & Schilling, 2007). Therefore, I expect innovating firms in less complex environments to engage in external commercialization agreements less frequently.

Conversely in more complex and highly uncertain environments innovating firms are under intense competitive and performance pressure and technical knowledge and access to markets is distributed among many firms in multiple segments of the industry (Porter, 1980; Powell et al., 1996). Innovating firms in complex environments are more motivated to engage in external commercialization of innovations for several reasons. First, there is a balance between firms in the industry such that there are likely to be incentives and opportunities for both parties to form an agreement (Ahuja, 2000; Chesbrough, 2007). Second, external commercialization, like other innovation agreements, can enhance performance resilience in these highly competitive markets (Eisenhardt & Schoonhoven, 1996). Findings show that more complex environments with higher uncertainty increase the number inter-firm agreements for innovation (Eisenhardt & Schoonhoven, 1996; Li & Atuahene-Gima, 2002). The patterns of these

agreements are more web-like with multiple nodes, and multiple relationships per firm (Rosenkopf & Schilling, 2007). Therefore I expect innovating firms in highly complex environments to engage in external commercialization agreements more frequently. Therefore I hypothesize:

> *Hypothesis 4: There is a positive relationship between environmental complexity and external commercialization.*

Chapter 2 began with a review of the literature on real options theory and introduced the appropriability framework. Next, the theoretical model integrating real options and the appropriability framework explained why firms may engage in external commercialization and the expected impact on firm performance. Finally, testable hypotheses were developed. The next chapter provides an overview of the methods used to test these hypotheses.

CHAPTER 3 METHODS

This Chapter describes the methodology used to test the hypotheses. The sample and data sources are identified followed by a description of the variables and measurement. The chapter concludes with an overview of the statistical analysis used to test the data.

Sample and Data Sources

Sample

The sample includes firms in the manufacturing sector with primary two-digit SIC codes between 20 and 39 (Cohen et al., 2000; Rothaermel & Alexandre, 2009; Schilling & Steensma, 2001). A comprehensive study period from 1990 – 2006 was selected. The sample was drawn from the Compustat database which contains accounting and financial data for firms traded on a North American exchange. I included data for firms designated on Compustat as both active and inactive to reduce survival bias. This allowed firms that entered and exited during the extended study period to be included in the sample. The initial set of 4,901 firms was screened to include firms that had reported the minimum seven years performance data required to measure prior and lagged performance in the study. This produced an initial sample frame of 2,895 firms from the Compustat database. The higher than anticipated incidence of missing data in the Compustat database resulted in elimination of an additional 1245 cases and a sample size of 1650. Outliers were diagnosed using the Cook's D test for influence at a threshold of 4/n (Bohon, forthcoming). This test identified 38 observations as outliers and 32 of these were omitted from the analysis. The final sample used in the analysis included 1618 firms in 11 industries. The distribution of industries represented in the sample is shown in table 3.1.

To identify which of the 1618 sample firms had participated in external commercialization, the sample was matched against the firm-level external commercialization

Table 3.1 Distribution of Sample Firms by Industry

Industry	SIC	Percent
Apparel and fabric products	23	2.3
Chemicals and pharmaceuticals	28	22.5
Concrete, stone, glass & related	32	1.5
Electronic components	36	21.8
Fabricated metals	34	2.4
Food and kindred products	20	4.8
Machinery and computers	35	17.4
Paper and allied products	26	2.6
Precision instruments incl. medical	38	17.0
Rubber and plastics	30	2.5
Transportation equipment	37	5.1
Total		100

data constructed from the SDC database. This data included 1438 firms that had participated in at least one external commercialization agreement during the study period. (Details of how this data was constructed are provided in the in the next section under the variable description for external commercialization). A total of 318 (19.7%) firms were matched using this procedure. Thus, the final sample of 1618 firms included 318 (19.7%) that had participated in external commercialization agreements during the study period from 1990 -2006. The number of external commercialization agreements per firm ranged from 1 to 32. The frequency of external commercialization agreements for the sample is shown in Table 3.3.

Data Sources

The dataset for this study was compiled from multiple archival sources including the Thomson Reuters SDC Platinum Joint Ventures and Alliances database, National Bureau of Economic Research Patent Data Project (PDP) and Compustat. Additional data is accessed from the National Bureau of Economic Research (NBER), U.S. Census Bureau Center for Economic Studies (CES) and U.S. Census of Manufacturers. These data sources are described below and summarized in Table 3.2.

Table 3.2 Frequency of External Commercialization Agreements

Number of Agreements	Number of Firms	Percent of Firms
0	1300	80.3
1	172	10.6
2	75	4.6
3	26	1.6
4 or more	45	2.8
Total	1618	100.0

SDC Platinum. The Statistical Data Corporation (SDC) Platinum database Joint Ventures and Alliances Module contains alliance information which is used in studies of alliances and innovation published in top strategic management journals (Anand & Khanna, 2009; Hagedoorn, Lorenz-Orlean & Van Kranenburg, 2009; Schilling, 2009; Steensma & Schilling, 2001). The SDC Platinum database contains global securities and financial data for publicly traded firms. The Joint Ventures and Alliances Module is of most interest in this study. This data reports a wide range of alliances including joint ventures, manufacturing and marketing agreements, licensing agreements and more, and can be filtered by alliance characteristics. Each alliance also reports "deal text", a synopsis which contains a detailed description of the agreement. According to Schilling (2009), the database contains more than 52,000 research or technology alliances from 1990 – 2005, and at least one alliance for each of 1,059 four-digit SIC codes. One noted caution of this database is that of underreporting (Hagedoorn et al., 2009). Although the database is compiled from an array of original sources including SEC filings, trade publications and news wires, most alliance types are not subject to mandatory reporting. Therefore the data likely represents a sample rather than a census of agreements. However, in a 2009 study comparing the most commonly used alliance datasets Schilling concluded that "These results provide some reassurance that even though each database only captures a sample

of alliance activity, it may yield reliable results for many - if not all- research purposes" (2009: p. 258). Details on how this data was used to construct the external commercialization variable are provided in the next section.

NBER. The National Bureau of Economic Research (NBER) Patent Data Project (PDP) database matches patent and patent citation data from the USPTO to Compustat North America data (Hall, Jaffe & Trajtenberg, 2001). NBER also publishes The Total Factor Productivity Index (TFP) used to measure the rate of technological change in this study.

U.S. Census of Manufacturers. The U.S. Census of Manufacturers provides periodic and comprehensive statistics about manufacturing establishments, activities, and production. Industry concentration ratios for the measurement of environmental complexity are extracted from this data.

Compustat. The Compustat North America database contains accounting and financial data for publicly traded firm in North America. Compustat data is used for measures of firm performance, R&D intensity, volatility, munificence and firm size.

Variables and Measures

The dependent, independent and control variables are described in this section. The mediator variable of interest - external commercialization - is treated as a count variable as discussed below. Each of the variable measures and data sources is summarized in Table 3.3.

Dependent Variable: Firm Performance

Firm Performance is measured by Return on Assets (ROA) computed at a four year time lag from the base year (Combs, Crook & Shook, 2005; Venkatraman & Ramanujam, 1986). The base year for performance measurement is the year of external commercialization, or the median year for firms that had multiple agreements. For firms that did not engage in external

commercialization the base years for performance were distributed to align with those of the external commercialization firms.

Independent Variables

In this section the measures for complementary assets, appropriability regime and environmental dynamism and complexity are described.

Complementary assets. Complementary assets are measured by a count of the number of 4 digit SIC codes for the firm. A larger number of SIC codes indicates that the firm is likely to have complementary resources and capabilities that enhance the ability to appropriate value from commercialization of innovation. For example, a manufacturer of electronic medical equipment for imaging (SIC 3844) may also develop software to operate the equipment (SIC 7372) and precision mechanical instruments for the procedure (SIC 3841). A count rather than a distance measure was employed because the proximity or distance between the secondary and primary SIC codes do not necessarily indicate more or less complementarity, as evidenced by the previous example.

Appropriability regime. Appropriability regime was previously defined as "the protection afforded the innovator by intellectual property protection and natural barriers to imitation" (Pisano & Teece, 2007: p. 279). Appropriability regimes tend to be homogeneous within industries and heterogeneous across industries (Cohen et al., 2000; Pisano & Teece, 2007). Following Arora & Ceccagnoli (2006), I constructed a measure of appropriability regimes at the industry level based on data reported from the Carnegie Mellon Survey (CMS). The Carnegie Mellon Survey (CMS) is a comprehensive survey of R&D managers in the manufacturing sector (see Cohen, Nelson & Walsh, 2000 for the full report). To measure the effectiveness of appropriability mechanisms the CMS survey asked respondents to "report the

percentage of innovations for which each appropriability mechanism had been effective in protecting the firm's competitive advantage from those innovations during the prior three years" (Cohen et al., 2000: p. 5). The response categories were < 10 percent, 10-40 percent, 41-60 percent, 61-90 percent and > 90 percent. The CMS data was collected for six different appropriability mechanisms- complementary assets for sales and service, complementary assets for manufacturing, lead time, patents, secrecy and other legal means - these are not mutually exclusive categories and the percentages need not sum to 100 percent. Product and process innovations were tallied separately reported in 34 ISIC (International Standard Industrial Classification: United Nations Statistics Division) groups.

To construct the appropriability regime variable for this study, I summed the percentages for patents, secrecy and other legal means across product and process innovations to create an index of effectiveness of appropriability regimes for each industry category. The value for the appropriability regime was assigned to each firm by matching the 2 or 3 digit SIC codes. The index ranges from 59 in the printing and publishing industry (SIC 27) to 154 in the medical equipment industry (SIC 384) with a mean of 113. A higher index indicates a stronger appropriability regime. Although the CMS survey also included complementary assets and lead time, these were excluded from the appropriability regime measure in this study because the definition of appropriability regime refers specifically to the protection of intellectual property.

Environmental dynamism. Similar to the appropriability regime and following previous literature, environmental dynamism and environmental complexity are appropriately measured at the industry level (Dess & Beard, 1984; Keats & Hitt, 1988). Environmental dynamism is indicated by the volatility as well as the rate of technological change in an industry (Dess & Beard, 1984; Eisenhardt & Schoonhoven, 1996; Keats & Hitt, 1988). Volatility is measured as

the standard error of the regression slope coefficient of annual revenue for all sample firms in an industry in the five years preceding the base year (Boyd, 1995; Goll & Rasheed, 1997; Keats & Hitt, 1988). This captures the deviation from the expected value of revenue in the industry (Dess & Beard, 1984).

Measuring the rate of technological change in a large, multi-industry sample presents a challenge, precluding measures of change such as rate of new product introduction or rate of firm entry and exit that are often used in single-industry samples (Upson, Ketchen, Connelly & Ranft, 2012). Schilling & Steensma (2001) applied a novel approach to measuring the rate of technological change in multi-industry studies. This measure is the Total Factor Productivity (TFP) growth index (Bartelsman & Gray, 1996). The TFP growth index is calculated as the growth rate of outputs minus the weighted growth rates of five factor inputs (capital, production and non-production labor, materials and energy). The TFP growth index is calculated and made available through the National Bureau of Economic Research (Becker & Gray, 2009). To align the TFP index with the relevant study period I averaged the TFP growth index from 1990 through 2005 and then assigned the index to firm-level data based on 2 or 3 digit SIC codes.

Environmental complexity. Consistent with the definition and previous research I use competitive intensity as a proxy for environmental complexity (Dess & Beard, 1984; Eisenhardt & Schoonhoven, 1996; Keats & Hitt, 1988). Competitive intensity is measured as an index of the four firm concentration ratio (Ceccagnoli, 2009; Schilling & Steensma, 2001). This measure is taken From The 1997 U.S. Census Of Manufacturers.

Mediating Variable: External Commercialization

I previously defined external commercialization as an organization's deliberate commercialization of technological knowledge to an outside organization, exclusively or in

addition to its internal application. Data for the external commercialization variable was obtained from the Thomson Reuters SDC Platinum Database. A broad query for all types of agreements that involved firms in the manufacturing sector during the period 1990-2006 returned 10,758 agreements. The data contained fields to indicate whether the agreement involved technology transfer and whether it included one or a combination of research and development, marketing, manufacturing or other types of activities. The "deal text" also provided a description of each agreement.

The description for each agreement was examined to determine whether the agreement was external commercialization or some other type of agreement and identify which party to the agreement transferred the technology. I applied conservative inclusion rules to avoid confounding external commercialization with myriad other types of co-operative agreements between firms. Principal among these inclusion rules was that the agreement must involve technology transfer. Technology transfer agreements may use alliance, licensing, joint venture, spin-out or other mechanisms and may also be embedded in a manufacturing or research and development agreement. Technology transfer agreements were typically identified by descriptions such as "entered into a license agreement, granted a license to use, received the right to use" or "contributed it's technology."

Agreements that did not include technology transfer were excluded from the operationalization of external commercialization. These agreements include brand licensing, contract manufacturing, OEM, and distribution agreements. Agreements that focused principally on operations were also excluded. These were usually described in the data as "joint venture to build and operate" or "joint venture to manufacture" (in a specific country) or "provide telecommunications services" in a country or region. Likewise, agreements that focused on

research and development described as “jointly develop” without further specification of technology transfer were considered research and development agreements only and therefore excluded from the agreements identified as external commercialization.

Several other types of agreements were excluded. For example, agreements that were strictly for software licensing it were excluded. I also excluded cross-licensing agreements in the telecommunications industry commonly known as “license pools” aimed at interoperability standards across providers and devices. Agreements in which technology was transferred from a not for profit research organization or government entity were also excluded. Although these agreements are considered technology transfer they were excluded from this study because the analysis is concerned with financial performance outcomes.

Of the 10,758 agreements that were returned by the initial search query, 2312 were considered external commercialization agreements. These agreements were then aggregated to the firm level resulting in a sample of 1438 manufacturing firms that had participated in at least one external commercialization agreement during the study period. These firms were then matched to the sample according to the procedure described previously. The external commercialization variable is operationalized as a count of the number of agreements the firm entered into during the study period 1990-2006.

Control Variables

A necessary but not sufficient condition for a firm to engage in external commercialization of innovation is that the firm own valuable technological knowledge that it can market to other firms. Technological knowledge may exist in the form of protected intellectual property such as patents. However, patent strategies and the propensity to patent vary across industries (Cohen et al., 2000). Therefore a simple patent count may underestimate the

store of knowledge assets a firm possesses. Therefore, I use measures of patents and R&D intensity to capture a more comprehensive measure of knowledge assets (Heeley, Matusik & Jain, 2007). Patents are measured by the number of patents assigned to the firm during the study period. The data is obtained from the NBER, Patent Data Project (PDP) database (Hall et al., 2001).

A control for alliances was included to control for the firm's propensity to form alliances of any type. Alliances is measured as a count variable of the total number of alliances formed by the focal firm during the study period, excluding those already classified as external commercialization. Data for the alliances was taken from the SDC Platinum database (Hagedoorn et al., 2009; Schilling & Steensma, 2001).

Environmental munificence refers to the availability of resources in the environment for growth (Dess & Beard, 1984; Sirmon, Hitt, Arregle & Campbell, 2010). Munificence is operationalized as a growth measure computed as the regression slope coefficient of annual revenue for all firms in an industry using time lagged for five years following the base year as the independent variable (Boyd, 1995; Dess & Beard, 1984; Goll & Rasheed, 1997; Keats & Hitt, 1988).

Prior performance is measured by ROA, calculated as a two-year average prior to the base year (Rothaermel & Alexandre, 2009). Firm size is measured by the number of employees in the base year. Firm age is calculated as the difference between the base year and founding year.

Statistical Analysis

The theoretical model specifies firm performance as the dependent variable and external commercialization as a mediator. Therefore I applied the Baron & Kenny (1986) recommended

approach to test for mediation. The hypothesis tests were conducted primarily using an ordinary least squares (OLS) approach with hierarchical loading (Hair, Black, Babin & Anderson, 2009). The exception to this was the test for the direct relationship between the independent variables and the mediator external commercialization.

External commercialization is a count variable with nearly 20% (318) of cases having at least one external commercialization agreement and 80% (1300) of cases having no external commercialization agreements. A Poisson regression is often the preferred method of analysis for count data (Tang He & Tu, 2012). However, the large number of zeros causes the distribution for external commercialization to be strongly skewed to the right, violating the assumption of the Poisson distribution for the mean and variance to be equal. The variance of external commercialization is more than five times larger than the mean indicating overdispersion in the distribution of the data. That is, greater variance than expected in a Poisson distribution. In cases of overdispersion the negative binomial regression is often more appropriate (Long & Freese, 2006).

The zero inflated negative binomial (ZINB) regression is an extension of the standard negative binomial method. The zero inflated method assumes that zeros result from two different processes. Structural or excess zeros are present because there was no chance of occurrence. For example a count of how many prizes were won would equal zero for all those who did not purchase any raffle tickets. This is different than a "real" zero in which raffle tickets were purchased but no prizes were won. The ZINB model has two components that predict the distinction between real zeros (i.e., company had no commercialization agreements) and excess zeros (i.e., company was coded zero because data were not provided) (Long & Freese, 2006). Several tests of model fit were applied to confirm that the ZINB was the best fit for the data. The

Vuong test compares the model fit of the standard NB with the ZINB regression (Tang et al., 2012). The alpha test compares the NB to the Poisson regression. The Stata "countfit" command is also useful for comparing alternative models for the data (Long & Freese, 2006).

This Chapter has outlined the methodology used to test the hypotheses in this dissertation. The sample, data sources, variable measures and analysis were explained. The next Chapter reports the results of this analysis.

Table 3.3 Constructs, Measures and Data Sources

Construct/ Variable	Measure	Data Source	Measurement Support
Dependent Variable			
Firm performance	Four year average Return on Assets (ROA) lagged from the base year	Compustat	Ceccagnoli, 2009; Rothaermel & Alexandre, 2009
Independent Variables			
Complementary assets	Count of 4 digit SIC codes	Compustat	Arora & Ceccagnoli, 2006
Environmental dynamism	Volatility: standard error of the regression slope of annual revenue for all sample firms in a 2-digit SIC industry	Compustat	Keats & Hitt, 1988, Boyd, 1995; Dess & Beard, 1984;
	Rate of technological change: TFP growth	2002 US Census of Mfg.	Schilling & Steensma, 2001
Environmental complexity	Concentration ratio of four largest firms in the industry	2002 US Census of Mfg.	Ceccagnoli, 2009; Schilling & Steensma, 2001
Appropriability regime	Effectiveness of proprietary knowledge protection in the industry	Cohen, Nelson & Walsh, 2000	Arora & Ceccagnoli, 2006; Ceccagnoli, 2009
Mediating Variable			
External Commercialization	Inter-firm agreements including technology transfer from the focal firm such as licensing, cross-licensing or spin outs.	SDC	Anand & Khanna, 2000a; Hagedoorn, Lorenz-Orlean & van Kranenburg, 2008; Schilling, 2009
Control Variables			
Technological knowledge	R&D intensity: R&D expense/Revenue	Compustat	Heeley, Matusik & Jain, 2007
	Patent count: number of patents assigned to the firm during the study period	NBER	Ahuja, 2000; McGrath & Nerkar, 2004
Alliances	Count of alliances formed during the study period, excluding external commercialization agreements	SDC	Schilling, 2009
Munificence	Five year average growth of annual revenue following the base year for all sample firms in a 2-digit SIC industry	Compustat	Dess & Beard, 1984; Goll & Rasheed, 1997
Firm prior performance	Two year average ROA prior to the base year	Compustat	Rothaermel & Alexandre, 2009
Firm size	Count number of employees	Compustat	Ceccagnoli, 2009
Firm age	Years since founding	LexisNexis	Ceccagnoli, 2009

CHAPTER 4 RESULTS

The results of the analysis are reported in three sections. The first section reports the results of the hypotheses tests. The next section describes several *post-hoc* tests. The last section proposes an alternative model specification.

Descriptive Statistics

Table 4.1 provides the descriptive statistics and correlations among the variables. Variance inflation factors (VIF) were examined and observed to be within recommended levels with most values less than 3 (Hair et al., 2009). The exceptions were the dummy variables created for industry controls, four of which exceeded a VIF of 10. I concluded that multicollinearity had little impact on the estimation results and all variables were retained in favor of complete model specification (Wooldridge, 2009).

Results of Hypothesis Testing

The theoretical model posits that external commercialization mediates the relationship between appropriability conditions and firm performance. These relationships were tested in the following hypotheses:

> *Hypothesis 1a: There is a positive relationship between complementary assets and firm performance.*
>
> *Hypothesis 1b: The commercialization decision mediates the positive relationship between complementary assets and firm performance. Specifically, less control over complementary assets will lead to increased levels of external commercialization and subsequent increased firm performance.*
>
> *Hypothesis 2a: There is a positive relationship between appropriability regime and firm performance.*
>
> *Hypothesis 2b: The commercialization decision mediates the positive relationship between the appropriability regime and firm performance. Specifically, a weaker appropriability regime will lead to increased levels of external commercialization and subsequent increased firm performance.*

Hypothesis 3: There is a positive relationship between environmental dynamism and external commercialization.

Hypothesis 4: There is a positive relationship between environmental complexity and external commercialization.

The hypotheses were tested in four models (Baron & Kenny, 1986). Model 1, shown in Table 4.2, tests the direct effects of the appropriability conditions on external commercialization using MLE in the form of a zero inflated negative binomial method (Tang, et al., 2012). Models 2 through 4 test the remaining relationships using OLS regression and results are shown in Table 4.3. Model 2 tests the direct effect of the appropriability conditions on firm performance. Model 3 tests the direct effect of external commercialization on firm performance. Model 4 tests the mediation effect of external commercialization on the relationship between appropriability conditions and firm performance.

Model 1. The first step in demonstrating support for the hypothesized mediation model is to establish a direct relationship between the appropriability conditions - complementary assets, dynamism, complexity and appropriability regime – and the mediator, external commercialization (Baron & Kenny, 1986). External commercialization is a count variable with nearly 20% (318) of cases having at least one external commercialization agreement and 80% (1300) of cases having no external commercialization agreements. Therefore a Zero Inflated Negative Binomial (ZINB) regression model is applied. Results of the Vuong test confirm that the ZINB is a better fit than the NB model (z=5.81; p<.001). Likewise the alpha test confirms that NB is a better model fit than a Poisson regression (χ^2=126.23; p<.001).

I applied a hierarchical approach by first entering the controls in the constrained model (Model 1) and then adding the independent variables in the full model (Model 2). Model 3 facilitates interpretation of the coefficients from the full model as incident rate ratio (odds ratios).

The results shown in Table 4.2 indicate that the overall model is significant (likelihood ratio χ^2 = 482.14; p <.001). Yet comparison of the fit indices suggests that the control model (1) is a better fit to the data than the full model (2). The differences for the Likelihood Ratio (6.49), McFadden's R^2 (-.06) and BIC (67.39) all indicate support in favor of the control model over the full model. This suggests that the incremental explanatory power of the full model was insufficient to accommodate the loss in degrees of freedom from the addition of five predictors into the model. To facilitate interpretation of the results the coefficient of each predictor was transformed to an incident rate ratio (odds ratio). The incident rate ratio (irr) represents how changes in the appropriability condition affect the rate at which external commercialization occurs (ceteris paribus). The percent increase or decrease can be calculated as 1 – irr. Values greater than 1 represent an increase in the likelihood of occurrence and values less than 1 represent a decrease. The results provided no support for the proposed relationships between the appropriability conditions and external commercialization. None of the coefficients were significant and the odds ratios are observed to be near 1.00, meaning that a change in the level of the predictor is likely to have no impact on external commercialization activity.[3] Contrary to expectations, the consistent lack of significance suggests that appropriability conditions are not good predictors of external commercialization activity. Therefore the mediation requirement for a direct relationship between the predictors and the mediator is not fulfilled. The remaining relationships are tested in Models 2–4.

Model 2. The second requirement for support of the mediation hypotheses is to show a significant relationship between appropriability conditions and the dependent variable, firm performance (Baron & Kenny, 1986). Results are shown in Table 4.3, Model 2. Controls were

[3] One exception to is the irr for volatility z = 1.35 (*ns*), se = 20.29.

Table 4.1
Descriptive Statistics and Correlations

	Variables	Mean	s.d.	1	2	3	4	5	6	7	8	9	10
1	Return on Assets	-.08	.30										
2	Industry 20	.05	.21	.09**									
3	Industry 23	.02	.15	.03	-.03								
4	Industry 26	.03	.16	.06*	-.04	-.02							
5	Industry 28	.22	.42	-.18**	-.12**	-.82**	-.09**						
6	Industry 30	.03	.16	.02	-.04	-.02	-.03	-.09**					
7	Industry 34	.02	.15	.04	-.04	-.02	-.03	-.09**	-.03				
8	Industry 35	.17	.38	-.01	-.10**	-.70**	-.08**	-.25**	-.07**	-.07**			
9	Industry 36	.22	.41	.06*	-.12**	-.81**	-.09**	-.29**	-.09**	-.08**	-.24**		
10	Industry 37	.05	.22	.07**	-.05*	-.04	-.04	-.12**	-.04	-.04	-.11**	-.12**	
11	Industry 38	.17	.38	-.03	-.10**	-.69**	-.07**	-.24**	-.07**	-.07**	-.21**	-.24**	-.11**
12	R & D	.66	3.48	-.31**	-.04	-.03	-.03	.24**	-.02	-.03	-.07**	-.06**	-.04
13	Patent Count	316.94	1650.37	.08**	-.04	-.03	-.01	-.03	-.02	-.02	.04	.08**	.02
14	Munificence	.05	.03	.05*	-.07**	-.68**	-.11**	-.21**	.18**	.02	-.14**	-.02	.09**
15	Prior ROA	-.09	.39	.53**	.06**	.59*	.06*	-.18**	.01	.04	.07**	.02	.05*
16	Firm Size	7.50	26.71	.12**	.11**	-.01	.04	-.02	-.01	-.02	-.03	-.02	.17**
17	Firm Age	27.92	30.49	.27**	.14**	.03	.10**	-.05*	.06*	.08**	-.02	-.07**	.08**
18	Alliances	1.63	5.84	.05*	-.04	-.02	-.03	.05	-.03	-.04	.06*	.05*	-.03
19	Complement. Assets	3.86	2.80	.20**	.07**	.11**	.11**	.00	.07**	.07**	-.07**	-.08**	.12**
20	Regime	119.97	20.09	-.21**	.19**	.01	.07**	.53**	-.06*	.05	-.34**	-.40**	-.23**
21	Volatility	.01	.01	.08**	-.10**	.01	.38**	-.04	.24**	.04	-.19**	.08**	-.10**
22	Tech. Change	.43	2.16	-.01	.03	-.10**	-.07**	-.37**	-.02	-.04	.73**	.07**	-.08**
23	Complexity	20.58	9.66	-.18**	-.22**	-.04	.02	.37**	-.21**	-.29**	-.01	-.30**	.58**
24	External Comm.	.45	1.54	-.01	-.05*	-.04	-.03	.13**	-.03	-.04	-.03	.04	-.04

Table 4.1 Continued

	Variables	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Return on Assets													
2	Industry 20													
3	Industry 23													
4	Industry 26													
5	Industry 28													
6	Industry 30													
7	Industry 34													
8	Industry 35													
9	Industry 36													
10	Industry 37													
11	Industry 38													
12	R & D	-.03												
13	Patent Count	-.04	-.03											
14	Munificence	.35**	-.04	.00										
15	Prior ROA	-.05	-.23**	.06*	.04									
16	Firm Size	-.09**	-.05*	.50**	-.01	.09**								
17	Firm Age	-.10**	-.11**	.20**	.01	.20**	.35**							
18	Alliances	-.06*	-.01	.66**	.00	.04	.36**	.10**						
19	Complement. Assets	-.11**	-.06*	.27**	-.02	.14**	.33**	.38**	.19**					
20	Regime	.24**	.20**	-.08**	-.04	-.21**	-.06*	-.12**	.00	-.06*				
21	Volatility	-.13**	.00	-.01	.09**	.04	.02	.09**	-.05*	.08**	-.06*			
22	Tech. Change	-.24**	-.11**	.09**	-.10**	.08**	.00	-.08**	.12**	-.08**	-.33**	-.12**		
23	Complexity	-.02	.17**	.01	-.05*	-.14**	.05*	-.17**	.07**	-.05	.28**	-.14**	.03	
24	External Comm.	-.05	.04	.48**	-.01	-.02	.22**	.05*	.64**	.13**	-.06*	-.04	.01	.09**

entered first, followed by the independent variables. A small but significant change in Adjusted R^2 was observed when the independent variables were added to the model ($\Delta R^2 = .01$; $p < .001$). Hypothesis *1a* suggested a positive relationship between complementary assets and firm performance as a baseline for the mediation effect. This relationship was supported ($\beta = .07$; $p < .01$) as expected (Ceccagnoli, 2009). Hypothesis *2a* suggested a positive relationship between the appropriability regime and firm performance. However, in contrast to prior literature this relationship ($\beta = .06$; *ns*) was not significant (Ceccagnoli, 2009). Finally the relationship between environmental factors and firm performance were tested (Dess & Beard, 1984). Environmental dynamism was tested using measures for volatility and technological change. Volatility was significant ($\beta = .06$; $p < .05$), however technological change was not ($\beta = -.06$; *ns*). Likewise, environmental complexity was not significant ($\beta = .07$; *ns*).

Model 3. The third condition for mediation is a direct effect of the mediator, external commercialization, on the dependent variable, firm performance (Baron & Kenny, 1986). Results are shown in model 3, Table 4.3. This relationship was not significant ($\beta = -.02$; *ns*) providing no support for this component of the relationship. Unfortunately, this precludes support for the mediation model as proposed, regardless of partial support that may have been provided by the other tests.

Model 4. Finally, the full model tests for the mediation effect of external commercialization (Model 4 Table 4.3). There was no observed change in the R^2 or the estimates for the independent variables when compared to Model 2. Thus, Model 4 is not significant, reinforcing the lack of support evidenced in the previous models.

Table 4.2 Negative Binomial Regression Results

Effects of Appropriability Conditions on External Commercialization (n=1618)

Variable	Model 1 Controls[a]	Model 2 Full Model[a]	Model 3 Incident Rate Ratio
Controls			
Industry controls were included (*ns*)			
Technological knowledge			
R&D intensity	-0.95	-0.91	0.98
Patent count	1.38	1.04	1.00
Munificence	-0.47	-0.53	0.29
Firm prior performance	1.77†	1.64†	1.34†
Firm size	-0.91	-1.10	1.00
Firm age	0.45	0.23	1.00
Alliances	5.80***	4.24***	1.05***
Independent Variables			
Complementary assets		-0.18	0.99
Appropriability regime		-0.90	0.99
Environmental dynamism			
Volatility		0.02	1.35
Rate of technological change		1.39	1.09
Environmental complexity		0.04	1.00
-2 Log Likelihood	-1041.74	-1038.49	
Likelihood ratio χ^2	475.63***	482.14***	
Δ Likelihood ratio χ^2		6.49	
McFadden's Adjusted R^2	.165	.159	
BIC	-9672.33	-9604.94	
Δ BIC		67.39	

[a] Standardized *z* scores

† p<0.10 * p<0.05, ** p<0.01, *** p<0.001

Table 4.3 OLS Regression Results

The Influence of Appropriability Conditions and External Commercialization on Firm Performance

Dependent Variable ROA Lagged 4 years (n=1618)

Variable	Controls	Model 2 Direct Effects	Model 3 Mediator Effects	Model 4[a] Full Model
Controls				
Industry controls were included				
Technological knowledge				
R&D intensity	-.18***	-.18***	-.18***	-.18***
Patent count	.00	- .02	.00	-.01
Munificence	.01	.00	.01	.00
Firm prior performance	.44***	.43***	.44***	.43***
Firm size	.00	-.01	.00	-.01
Firm age	.15***	.11***	.15***	.11***
Alliances	.03	.05	.03	.06
Independent Variables				
Complementary assets		.07**		.07**
Appropriability regime		-.06		-.06
Environmental dynamism				
Volatility		.06*		.06*
Rate of technological change		-.06		-.06
Environmental complexity		-.07		-.07
Mediating Variable				
External Commercialization (EC)			-.02	-.02
Adjsuted-R^2	.34	.35	.34	.35
Δ Adjusted R^2		.01***	0.00	0 .00
F-Stat	50.49***	41.24***	47.70***	39.46***
Δ F-Stat		6.71***	.62	.57

a. Model 4 is in comparison to model 2

* p<0.05, ** p<0.01, *** p<0.001

Post-hoc Tests

In view of the lack of support for the expected relationships, several post-hoc tests were conducted. First, I ran the regression model using the Preacher and Hayes (2004) recommended bootstrapping approach to mediation. Results were similar to the Baron and Kenney approach. Tests for indirect effects were not significant. The test (homogeneity of interaction) for a mediation effect across different levels of the independent variables were also not significant.

Constrained samples. In one set of tests I used constrained samples to test the robustness of the results. The first subsample was a matched sample of 636 firms with equal representation of those that had engaged in external commercialization and those that had not (318 firms in each group). The purpose was to test whether the excessive number of firms with zero external commercialization agreements was driving the results. The same method as above was applied to this sample with the exception that the negative binomial regression did not include the extension for zero inflation. Echoing the initial results, the fit indices favored the control model over the full model (Δ-2LL=6.42; $\Delta \chi^2$=12.84; ΔMcFadden's R^2=0.0; and ΔBIC=19.44) and there were no significant effects for the influence of appropriability conditions on external commercialization. The remaining tests were conducted as before. There was evidence of a negative relationship between the rate of technological change and firm performance (β = -.14;p <.05). However there was no support for external commercialization as a mediator in the full model (ΔR^2=0; ns).

Another subsample of 1362 firms that excluded 256 firms in the pharmaceutical industry (SIC 283) was also tested. The pharmaceutical industry is unique in the high patent rate and presence of contract research organizations that perform the research and development function and then commercialize externally through large pharmaceutical companies. Results of the ZINB

regression show the control model is a better fit to the data than the full model (Δ-2LL=7.24; Δ χ^2=14.85; ΔMcFadden's R^2=0.1; and ΔBIC=57.4). The direct relationships between the appropriability conditions and firm performance were similar to the full sample in that complementary assets (β = .08; p < .01) and volatility (β = .09; p < .01) exhibited positive relationships with firm performance. However, unlike the initial model technological change (β = .48 p < .05) and complexity (β = -.90; p < .01) were also significant. The appropriability regime effects remained insignificant as did the mediating effect of external commercialization (ΔR^2=0; ns).

Finally, a subsample containing only 318 firms that had engaged in external commercialization was tested to discover the effect of the frequency of external commercialization activity among those firms that had used this strategy. The main effect of the appropriability conditions on external commercialization was tested using a standard Negative Binomial regression. The fit indices (Δ-2LL=3.56; Δ χ^2=7.13; ΔMcFadden's R^2=0.0; and ΔBIC=21.68) expressed persistent preferences for the control model over the full model. Examination of the full model did show a significant relationship for the effect of complementary assets on external commercialization (β = 2.20, irr = 1.04; p < .05). The remaining mediation relationships were tested using OLS as above. The full model had an Adjusted R^2 of .45 (ΔR^2=0; ns). There were no significant effects of the appropriability conditions or external commercialization (β =.01; ns) on firm performance.

External commercialization as a binary variable. An additional post-hoc test was conducted to check whether the measurement of external commercialization influenced the results. This time the variable was operationalized as a dichotomous variable with 1 representing firms that had engaged in external commercialization and 0 for those that had not. Results of the

binomial logit regression were significant for the effect of complementary assets (odds ratio .92; p<.05) and environmental complexity (odds ratio 1.04; p<.01) on external commercialization. However fit indices continued to show the control model a better fit to the data. Consistent with the results of the hypothesized model, tests for mediation show that complementary assets (β = .06; p < .01) and volatility (β = .06; p < .05) have a direct effect on firm performance. However, there was no support for a mediation effect.

Tests of influence. A robustness test was conducted to check whether the (32) outliers previously omitted from the analysis would influence the results. The models were analyzed with 1650 observations. However the zero inflated negative binomial model failed to converge using the full data set. Visual examination of the leverage versus residual squared plot showed seven observations that appeared to be truly problematic and these were deleted. The models were run again using the remaining 1643 observations. The indicators of model fit were similar to the original results, as were the significance and magnitude of the regression coefficients. Thus, although the original omission of outliers may have been aggressive in eliminating points of influence, this did not affect the results

Exclusion of industry controls and alternatively specified inflator. I also had concerns that the industry controls may have attenuated the overall results for the model because industry factors were accounted for in the independent variables. Specifically appropriability regime, environmental dynamism and environmental complexity were measured at the industry level. Thus, an alternative model excluding industry controls was tested in a post-hoc analysis.

In this model I also altered the model for the zero inflated negative binomial regression. In this model an additional variable was introduced specifically to predict the excess zero's in the data. According to Long and Freese (2006) the variable specified for the inflate portion of the

equation should be specifically targeted at predicting excess zeros and may not necessarily be one of the variables in the model being tested. Thus, I specified External Commercialization Intensity in the inflate component of the ZINB equation. External Commercialization Intensity is a measure of the percentage of firm revenue received from licensing, aggregated at the industry level. The data are sourced from the 2002 Census. Because a census measure offers a better representation of the true magnitude of activity compared to other data sources, it is ideal for predicting excess zeros due to underreporting compared to real zeros due to a firm's inactivity in external commercialization. The ZINB estimation equation for the full model in STATA is:

DV = Controls (excluding industry dummies) IVs, inflate (EC intensity)

Consistent with prior results, the post-hoc tests for the direct effects of the independent variables on the mediator shown in Table 4.4 indicates the control model is a better fit for the data than the full model (Δ-2LL= 11.01; $\Delta\chi^2$= 22.02; ΔMcFadden's R^2=-.01; and ΔBIC=14.93). However, in an improvement from the original model, the variables for complementary assets (β= -1.73; $p < .10$), appropriability regime (β= 2.62; $p < .01$), and environmental complexity (β= 1.67; $p < .10$) were significant. Likewise, the results of the OLS regression shown in Table 4.5 failed to support a mediation effect. However improvements in the significance of the independent variables were observed for complementary assets (β= .06; $p < .01$), appropriability regime (β= -.08; $p < .001$) and rate of technological change (β= -.08; $p < .001$).

Alternative Model Specification: Moderation

Although the tests of the proposed model produced no support for the original hypotheses, further investigation revealed interactions between appropriability conditions and firm performance. Moderating relationships were tested using OLS regression in Models 1-3

Table 4.4 *Post-hoc* Industry Controls Excluded

Negative Binomial Regression Results - EC Intensity Predictor

Effects of Appropriability Conditions on External Commercialization (n=1618)

Variable	Model 1 Controls[a]	Model 2 Full Model[a]	Model 3 Incident Rate Ratio
Controls			
Technological knowledge			
R&D intensity	1.71†	1.47	1.02
Patent count	-.05	.51	1.0
Munificence	.02	.09	1.19
Firm prior performance	-2.72 **	-1.73†	.80
Firm size	.81	.92	1.0
Firm age	-1.74†	-1.02	1.0
Alliances	5.27***	4.91***	1.13
Independent Variables			
Complementary Assets		-1.73†	.95
Appropriability regime		2.62 **	1.01
Environmental dynamism			
Volatility		1.1	
Rate of technological change		-.93	.97
Environmental complexity		1.67†	1.01
-2 Log Likelihood	-1128.88	-1139.89	
Likelihood ratio χ^2	301.36***	279.34***	
Δ Likelihood ratio χ^2		22.02	
McFadden's Adjusted R^2	.105	.101	
BIC	-9579.33	-9594.26	
Δ BIC		14.93	

[a] Standardized *z* scores

† p<0.10 * p<0.05, ** p<0.01, *** p<0.001

Table 4.5 *Post-hoc* Industry Controls Excluded

OLS Regression Results

The Influence of Appropriability Conditions and External Commercialization on Firm Performance

Dependent Variable ROA Lagged 4 years (n=1618)

Variable	Controls	Model 2 Direct Effects	Model 3 Mediator Effects	Model 4[a] Full Model
Controls				
Technological knowledge				
R&D intensity	-.19***	-.18***	-.19***	-.18***
Patent count	0.0	-.02	0.0	-.01
Munificence	.03	.01	.03	.01
Firm prior performance	.45***	.43***	.45***	.43***
Firm size	.01	0.0	.01	0.0
Firm age	.16***	.12***	.16***	.12***
Alliances	.03	.04	.025	.05
Independent Variables				
Complementary Assets		.06**		.06**
Appropriability regime		-.08***		-0.0***
Environmental dynamism				
Volatility		.03		.03
Rate of technological change		-.08***		-.08***
Environmental complexity		-.04†		-.04†
Mediating Variable				
External Commercialization (EC)			.03	.03
Adjsuted-R^2	.34	.36	.34	.36
Δ Adjusted R^2		.02***	.001†	0.0
F-Stat	118.71***	74.27***	103.22***	68.26***
ΔF-Stat		8.3***	2.91†	.87

a. Model 4 is in comparison to model 2

† p<0.10 * p<0.05, ** p<0.01, *** p<0.001

shown in Table 4.6. The controls are entered in Model 1, followed by the direct effects in Model 2 and the interaction effects in model 3. There is a significant change in R^2 from Model 2 (R^2=.35) to Model 3 (R^2=.36). Model 3 also shows significant interaction effects for the rate of technological change (β = .07; p < .01), environmental complexity (β = -.08; p < .05) and the appropriability regime (β = .10; p < .01). However there was not a significant interaction effect for complementary assets (β = -.03; ns) or volatility (β = -.03; ns).

To better interpret the moderation effects, the significant interactions were plotted in Figures 4.1- 4.3 (Cohen & Cohen, 1983). Figure 4.1 illustrates that at high levels of external commercialization high rates of technological change are associated with moderate increases in ROA. Conversely, at low levels of external commercialization higher rates of technological change decreases ROA. Thus, external commercialization reduces the otherwise negative effect of the rate of technological change on ROA. The moderation effect of external commercialization on environmental complexity is shown in Figure 4.2. Here we observe that high external commercialization strengthens the negative relationship between environmental complexity and ROA. However, when external commercialization is low environmental complexity has limited effect on ROA. Finally, Figure 4.3 shows that at high levels of external commercialization, high appropriability regimes are associated with increases in ROA. Conversely, at low levels of external commercialization high appropriability regimes are associated with decreasing ROA. Further discussion of these interactions is reserved for the next chapter This chapter reported the results of the hypothesis tests and several post-hoc tests. Alternative model specifications were also tested. These results are discussed in the next chapter.

Table 4.6 Alternative Model Specification

Moderating Effects of External Commercialization on Firm Performance

Dependent Variable ROA Lagged 4 years (n=1618)

Variable	Model 1 Controls	Model 2 Direct Effects	Model 3 Interactions
Controls			
Industry controls were included			
Technological knowledge			
R&D intensity	-.18***	-.18***	
Patent count	.00	- .02	
Munificence	.01	.00	
Firm prior performance	.44***	.43***	
Firm size	.00	-.01	
Firm age	.15***	.11***	
Alliances	.03	.05	
Independent Variables			
Complementary assets		.07**	
Environmental dynamism			
Volatility		.06*	
Rate of technological change		-.06	
Environmental complexity		-.07	
Appropriability regime		-.06	
Moderating Variable			
External Commercialization (EC)		-.02	
Interactions			
EC x Complementary assets			-.03
EC x Appropriability regime			.10**
EC x Volatility			-.03
EC x Rate of technological change			.07**
EC x Environmental complexity			-.08*
Adjsuted-R^2	.34	.35	.36
Δ Adjusted R^2		.01***	.01***
F-Stat	50.49***	39.46***	32.97***
Δ F-Stat		7.29***	2.34*

* p<0.05, ** p<0.01, *** p<0.001

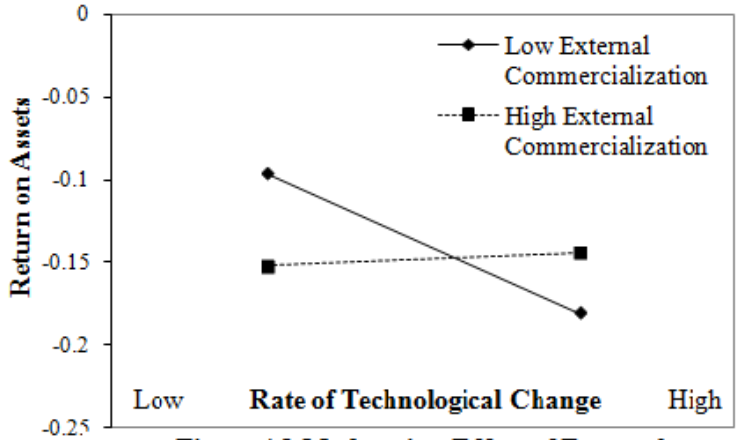

Figure 4.1 Moderation Effect of External Commercialization on Rate of Technological Change

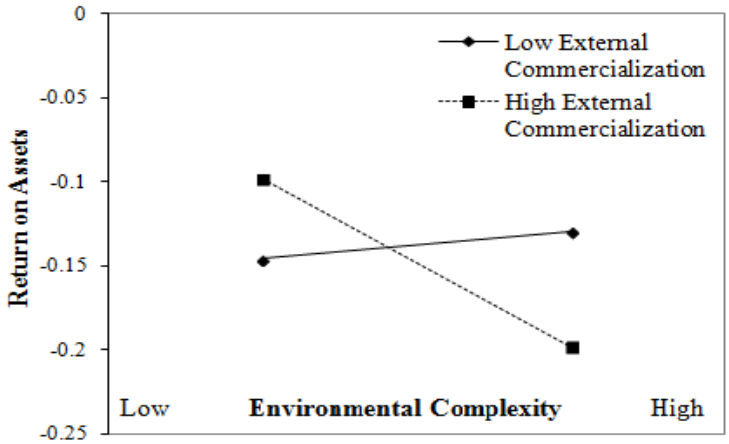

Figure 4.2 Moderation Effect of External Commercialization on Enviornmental Complexity

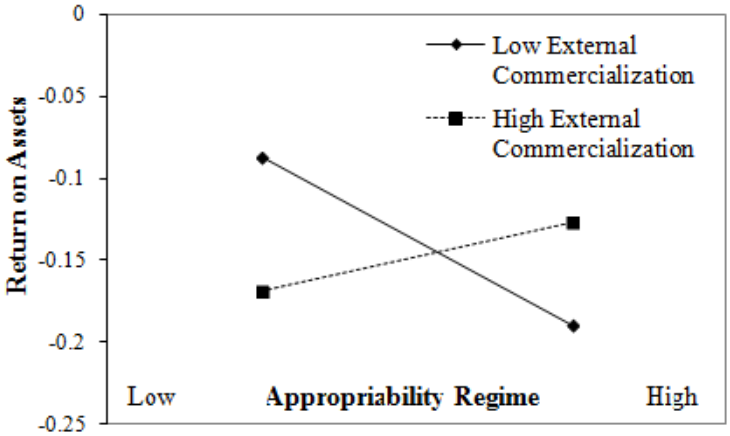

Figure 4.3 Moderation Effect of External Commercialization on Appropriability Regime

CHAPTER 5 DISCUSSION AND CONCLUSIONS

This Chapter provides a discussion of the study findings in four sections. In the first section I provide an overview of the study and discuss the overall findings. Specific results for each hypothesis and insights from additional findings are also discussed. Next, I take stock of the theoretical, empirical and practical contributions of the study. Finally, I address limitations and suggest directions for future research.

Overview

Innovation has been identified as a source of competitive advantage (Hamel, 2000). Indeed investment in innovation has grown on a worldwide basis (NSF, 2010). Yet, firms are challenged to earn a return on this investment in innovation (Teece, 1986; Thomas & D'Aveni, 2009). External commercialization may be one strategy firms can employ to increase the value appropriated from their investment innovation. Prior literature has provided logic for external commercialization and evidence of the factors that lead a firm to engage in external commercialization (Arora & Gambardella, 2010a; Chesbrough, 2003). However the literature is lacking in a strategic theoretical grounding as well as evidence linking external commercialization to firm performance.

Understanding whether, and under what conditions, external commercialization has performance advantages is a needed extension of the current literature (Walter, 2012). It is also vital to understand the performance consequences of an external commercialization strategy in providing guidance to managers seeking returns on their investment in innovation. Further, a strategic theoretical approach is needed to position external commercialization firmly within the strategy literature. Two research questions emerged from this need.

1. What conditions influence the extent to which a firm engages in external commercialization?

2. Does external commercialization influence firm performance?

I applied the theoretical lens of real options theory to investigate the drivers and performance consequences of external commercialization. The firm's initial investment in technological knowledge has been positioned in the literature as an irreversible investment that provides the firm with an option to commercialize the innovation in the future (McGrath, 1997, Miller, 2002). The option is valuable because it provides managerial flexibility to hold, abandon or exercise an option in uncertain environments (Amram & Kulatilaka, 1999; Dixit & Pindyck, 1994).

To further develop the theoretical model, I integrated the constructs of the appropriability framework (Teece, 1986) with real options theory. More specifically, the model proposes that the appropriability conditions of complementary assets (irreversible investment), appropriability regime and market timing (uncertainty) will influence the external commercialization decision (managerial flexibility). Accordingly, managers are expected to select a commercialization strategy that enhances the level of appropriation and firm performance. Thus, external commercialization mediates the relationship between appropriability conditions and firm performance. Hypotheses were derived from this model and tested in a large scale empirical design.

Discussion of Research Findings

As a whole, the results reported in Chapter 4 do not provide support for the hypotheses. The first part of this discussion takes holistic perspective, examining the lack of findings overall. This is followed by a more detailed discussion of each hypothesis. Finally, the findings from the alternative model specification are explored.

Taken together, the results do not provide evidence of a real options approach to external commercialization of innovation. External commercialization is, in the main, a strategy of incremental returns (Grindley & Teece, 1997; Walter, 2012). It was proposed here as untapped potential for firms that were not well positioned to appropriate value from direct commercialization of their innovation. The returns were not expected to exceed those of direct commercialization under strong appropriability conditions (Teece, 1986; Rivette & Kline, 2000). Thus, providing evidence of significant relationships for what was posited as incremental returns was an inherent challenge in this research.

At the same time I recognized that external commercialization is an underutilized strategy. Indeed, the motivation for the study was driven in part by the potential for managers to consider this strategy more often as a way to increase returns on the investment in innovation. The analytical method and the post-hoc tests provided some assurance that the large number of firms that had no external commercialization activity was not driving the results. However, I cannot rule out the influence that the low frequency of external commercialization among firms did use this strategy may have had on the results. The low utilization combined with marginal returns may have made it particularly difficult to detect a relationship with the return on assets performance measure (Combs, et al., 2005). A performance measure that is more proximate to external commercialization may be better suited to uncover the expected returns from this strategy (Walter, 2012).

Finally, it is possible that the returns from external commercialization are in fact not appropriated by the focal firm to the extent proposed (Crook, Ketchen, Combs & Todd, 2008; Teece, 1986; Winter, 2006). Indeed, the challenge of appropriating value from innovation was a

major motivation for this study. Having provided explanations for the overall results, I now turn to a discussion of each hypothesis.

Hypothesis 1a and b: complementary assets. In Hypothesis 1, I reasoned that firms faced with weak complementary asset positions were likely to use an external commercialization strategy to enhance performance. Consistent with prior literature, the positive relationship between complementary assets and firm performance (H1a) was significant (Tripsas, 1997). However the results did not support the mediation effect of external commercialization. Complementary assets did not have an influence on external commercialization, nor did external commercialization influence firm performance (H1b).

These results confirm the underlying premise that strong complementary asset positions have a positive influence on the firm's ability to appropriate value from its own innovation (Teece, 1986). Yet the results suggest that external commercialization does not play a role in this relationship. One explanation may be that firm's use other types of agreements to compensate for their lack of complementary assets (Ahuja, 2000; Stuart, 2000). For example, manufacturing or marketing agreements provide the firm with access to appropriation enhancing complementary assets but fall outside the definition of external commercialization (Adner & Kapoor, 2010). Although alliance agreements of all types were controlled for, it may be more appropriate to include them in the operational definition and measurement of complementary assets (Walter, 2012). This could provide a sharper distinction between the levels of complementary assets available to the firm.

Hypothesis 2a and b: appropriability regime. Consistent with real options reasoning, I hypothesized that firms operating in weak appropriability regimes could use an external commercialization strategy to appropriate some value from innovation (Vanhaverbeke et al.,

2008). The absence of a direct relationship between appropriability regime and firm performance was surprising (H2a), given that this has been established in prior literature (Ceccagnoli, 2009). Neither did the evidence support a mediated relationship (H2b). The appropriability regime did not have a significant influence on external commercialization and external commercialization did not affect firm performance.

One explanation for the overall lack of significance associated with the appropriability regime may lie in level of analysis used to measure this variable. The literature provides ample foundation to use an industry-level measure (Cohen et al., 2000) on the basis that appropriability regimes tend to be homogeneous within, and heterogeneous across, industries (Pisano & Teece, 2007). Yet an industry level measure may not be fine-grained enough to detect differences in the individual firm's ability to protect their intellectual property. A measure that includes firm-level indicators of protection such as patent lawsuits or patenting intensity relative to the industry may be more productive in testing this relationship. In addition, and contrary to the hypothesized relationship, some studies have found that firms in tighter appropriability regimes are more likely to license technology precisely because they can protect it (Ceccagnoli, 2009; Fosfuri, 2006). It is possible that the results are confounded by these offsetting effects.

Hypothesis 3: environmental dynamism. I hypothesized that external commercialization would increase with the level of environmental dynamism (Chen et al., 2010; Rosenkopf & Schilling, 2007). Two dimensions of environmental dynamism were considered in the model - volatility and the rate of technological change in the industry. The results for Hypothesis 3 did not support a relationship with external commercialization for either dimension.

Hypothesis 4: environmental complexity. I hypothesized that more complex environments would lead to more external commercialization (Ahuja, 2000; Eisenhardt & Schoonhoven, 1996). However, the relationship was not supported. One explanation for this may be that differences in the level of environmental complexity do not result so much in more or less frequency of external commercialization, but different patterns of agreements (Rosenkopf & Schilling, 2007). Likewise, different patterns of agreements, for example between industry leaders and smaller firms versus equally balanced competitors, are expected to have varying returns to the focal firm due to bargaining power (Porter, 1980).

In addition, the literature upon which Hypothesis 4 was developed applied to the frequency of all types of inter-firm agreements (Li & Atuahene-Gima, 2002, Stuart, 2000). Although extrapolation of the literature to external commercialization agreements is a logical step, certainly these are a small portion of the total number of inter-firm agreements captured by these studies. Idiosyncrasies or boundary conditions may apply to external commercialization agreements that do not apply in the more general case of inter-firm agreements (Walter, 2012), contributing to the lack of findings for Hypothesis 4.

Insights from Additional Findings

Given the absence of the expected relationships between the constructs of interest I formulated a *post-hoc* investigation of an alternatively specified model. This model posited a moderated, rather than a mediated, relationship between external commercialization and the variables previously tested. The results produced significant interactions for appropriability regime, rate of technological change (dynamism) and environmental complexity, with external commercialization. This suggests that the alternatively specified model of moderation may be a

more appropriate representation of the relationships than the originally proposed mediation model.

In the alternative model, external commercialization moderated the influence of the appropriability regime on firm performance. Specifically, higher levels of external commercialization in tight appropriability regimes were associated with increases in performance (Figure 4.3). Although this interaction effect was not hypothesized, it is consistent with prior literature that shows a positive relationship between the strength of the appropriability regime and the propensity to license (Arora & Ceccagnoli, 2006; Cohen et al., 2000).

The alternative specification for moderation also produced a significant interaction of technological change with external commercialization. Specifically low levels of external commercialization in environments with high rates of technological change were associated with a decreasing return on assets, while higher levels of external commercialization had little effect on performance across high and low rates of technological change (Figure 4.1). This is consistent with the original logic presented in the hypotheses, that environments of rapid technological change provide opportunities for firms to introduce new technologies and garner momentum for adoption of these technologies (Tushman & Anderson, 1986; Utterback & Abernathy, 1975). However the asymmetric pattern of returns in the interaction suggest that the opportunity cost of not putting the technology into the fray may be greater than the incremental return appropriated from external commercialization (Grindley & Teece, 1997 Pisano & Teece, 2007; Winter, 2006). Indeed firms that do not leverage market timing are likely to find their technologies left behind (McGrath, 1997).

The interaction of environmental complexity with external commercialization was also significant in the alternative model. The results show that high external commercialization in

high complexity environments is associated with decreasing ROA, while low levels of external commercialization have little effect on ROA (Figure 4.2). One explanation for this finding is that the risk of imitation is greater in complex environments with relatively more balanced competitors vying for technological dominance (McGrath, 1997). Thus external commercialization appears to be risky when the potential benefits of technology diffusion are offset by the loss of appropriation to other industry participants (Alexy & Reitzig, 2012; Coff & Laverty, 2001: Lavie, 2006).

The results of the *post-hoc* specification with the industry controls excluded are also worth noting. Industry controls were included in the primary study because of the possibility that unobserved heterogeneity at the industry level could influence the results. However, because the industry level variables relevant to the study are included as predictors in the model I also had to consider the likelihood that the controls were attenuating the effects of the predictors. The removal of the industry controls did not change the results for the overall models or the mediation effect. The Adjusted R^2 (.36) was the same in both models. However, there was a change in the level of significance for the industry-level predictors. Appropriability regime changed from β= -.06; *ns* to β= -.08; $p < .001$. Rate of technological change also shifted from β= -.06; *ns* to β= -.08; $p < .001$ and environmental complexity was marginally significant (β= -.04). These results suggest that the more parsimonious model without industry controls effectively explains the outcomes with minimal risk of under-specification.

Contributions

Notwithstanding the lack of empirical results in this dissertation, some contributions have been made. These contributions lie in the theoretical extensions and intersections of the current literature. Real options theory has been previously applied to innovation strategy

(McGrath, 1997), and as a financial model for funding research and development (Amram & Kulatilaka, 1999). However, real options theory has not been previously applied to open innovation or the external commercialization decision. Scholars of open innovation such as Chesbrough (2003) have suggested that real options may have potential to provide the theoretical grounding needed in the open innovation and external commercialization literature. Reflecting on the theoretical grounding for external commercialization, Arora & Gambardella (2010a) observed that the antecedents of licensing activity are often based on the appropriability framework, but lack a richer theoretical foundation. They highlighted the need for a more strategic theoretical explanation for licensing activity, beyond the current economic view of the boundaries of the firm. This dissertation provides this strategic lens through the application of real options theory. In sum, the application of real options theory at the intersection of the appropriability framework and external commercialization provides a unique contribution to the literature.

From an empirical perspective I set out to make a contribution by testing a set of hypotheses which span the motivations and performance consequences of external commercialization. The lack of empirical support found in this study means that this contribution cannot be made as originally proposed. However progress has been made. The lack of support for the hypothesized relationships may imply that boundary conditions act in a contingent manner as suggested by the *post-hoc* results for the moderation model. Indeed, these boundary conditions may also be more finite than could be detected in this high level study. This is productive in pointing to future research that examines external commercialization at a more detailed level.

Similarly, provision of practical guidance to managers is also precluded by the lack of empirical support found in this study. Yet, this is also instructive. It is likely that external commercialization is advisable only under specific conditions. As suggested in the preceding paragraph, a finely grained study aimed at detecting tighter boundary conditions may provide more specific insights needed to provide recommendations for managers. This future research is discussed in the following section.

Limitations

Notwithstanding the methodological rigor applied in this study, some limitations remain. Alliance data, including agreements that fit the definition of external commercialization, are subject to under-reporting (Schilling, 2009). Although the data includes a broad scope of primary sources, there are no regulatory requirements for reporting these contractual relationships. Therefore the data probably represents a sample rather than a population of agreements. However, Schilling (2009) reported consistent results across different datasets which provided some confidence that the data is representative.

In addition, return on assets is just one measure of firm performance that may not fully reflect the value appropriated from a firm's innovation activity (Crook et al., 2008). One study has measured the returns from external commercialization using abnormal stock returns (Walter, 2012) and performance measurement using alternative measures such as Tobin's Q, market share or return on sales may also be fruitful (Combs et al., 2005). A finer-grained analysis of the innovation value appropriated by the firm and by other participants conducted at the product-market level may be necessary to understand the full gamut of appropriation from innovation (Amit & Schoemaker, 1993; Lavie, 2006).

Finally, in applying real options theory and the appropriability framework to external commercialization I did not address individual-level behavioral factors that may influence the technology commercialization decision. Indeed some of the debate surrounding real options theory highlights these very issues (Adner & Levinthal, 2004a; Barnett, 2008; McGrath et al., 2004). Option traps are one manifestation of how managerial behavior influences the commercialization decision (Adner & Levinthal, 2004a). Option traps contribute to managerial reluctance to abandon investments as well as reluctance to exercise options. Option traps are driven in part by the psychological tendency to escalate commitment (Brockner, 1992; Staw, 1981). The escalation of commitment is one example of a behavioral factor that was not included in this study and may have contributed to the lack of findings.

Future Research

Some of the findings from this study, albeit limited, do provide direction for future research. First, the specification for a moderated relationship did indicate an interaction between external commercialization and the effect of appropriability conditions on firm performance. This specification should be pursued and could be augmented by a sharpening of measures as discussed previously in this Chapter.

The findings also point to a strong relationship between external commercialization and other types of alliances. External commercialization is only one type of inter-firm agreement. The decision to commercialize a technology externally is not likely to be made in isolation, but rather in the context of a broader innovation strategy as well as other types of inter-firm agreements (Ahuja, 2000; George, Zahra, Wheatley & Khan, 2001). I envision two paths for potential investigation, both of which would leverage a real options approach.

First, external commercialization could be viewed as an initial investment in a relationship that provides the focal firm with an option to increase the level of commitment to the relationship in the future. Licensing may be a means to enter a simple arms length contractual relationship that enables the focal firm to gain experience with the partner and reduce the uncertainty associated with entering a more extensive relationship such as research and development alliances or joint ventures. If a time series analysis revealed that external commercialization occurs early in a sequence of relationships between the same firms, this may provide evidence that firms use licensing as a nested option to establish relationships with other firms.

A second study could examine external commercialization in the context of a larger innovation strategy. Indeed firms that employ open innovation strategies may develop innovations internally or source them externally, as well as commercialize these innovations internally or externally. Previous research has examined the complementarity of external knowledge sourcing and internal research and development in the context of absorptive capacity (Rothaermel & Alexandre, 2009).[4] Similarly, investigation of the complementarity between external commercialization and the other innovation strategies is also worthwhile.

Opportunities to extend this study to include individual-level cognitive factors should also be pursued. For example, resistance to open innovation in general and external commercialization in particular, sometimes referred to as the not invented here and not sold here syndromes may be due to mangers cognitive inertia connected to a tradition of vertically integrated innovation strategies (Chesbrough, 2003). This may be an additional reason for

[4] Absorptive capacity and learning also provide an interesting context for investigation of external commercialization. That is, can firms actually learn to do this well? Lichtenthaler (2009) described this notion as desorptive capacity – a firms' capability to transfer knowledge out, rather than transfer knowledge in.

underutilization of a potentially beneficial strategy. Understanding causes and interventions related to cognitive inertia may facilitate effective implementation of open innovation strategies (Reger, Gustafson, Demarie & Mullane, 1994).

Alternatively, external commercialization may be inhibited because managers simply do not recognize potential outlets for their technologies (Rivette & Kline, 2000). Managerial focus on developing and commercializing technologies internally may preclude recognition of external opportunities (Busenitz & Barney, 1997). If these opportunities are distant from the core technology or industry, managers may not perceive the opportunity as relevant to them (Haynie, Shepherd & McMullen 2009). Thus, future research could incorporate a cognitive approach by considering the moderating effect of opportunity recognition on external commercialization (Bingham, Eisenhardt & Furr, 2007).

Finally, the institutional environment was not addressed in this study. The investment in technological knowledge is conducted in complex and ambiguous task environments and decisions are made by managers who are subject to bounded rationality (Cyert & March, 1963; Duncan, 1972). Faced with the decision to commercialize technology managers decisions are likely to be influenced by institutional pressures and interpretive schemes that call for different types of investment decisions (Reus et al., 2009). Likewise, Barnett (2008) has proposed that formal and informal institutional structures are likely to shape managerial attentiveness and options decisions. Accordingly, future research integrating an institutional and cognitive lens may be productive in providing an explanation of commercialization of technological knowledge.

With regard to the methodological approach, I investigated external commercialization by analyzing quantitative archival data to test hypotheses. This approach is typical of maturing

streams of research, and is also likely to provide incremental contributions to the literature (Edmondson & McManus, 2007). Moving the literature forward at this juncture may require a rigorous qualitative approach that taps a deeper understanding of contemporary innovation processes. A multi-method qualitative study of a small sample of "serial licensors" could make such a contribution. A qualitative design could include unobtrusive thematic content analysis followed by semi-structured interviews with the managers responsible for innovation (Langley, 1999). This methodological approach has potential to uncover new propositions and constructs to move the literature forward in a meaningful way (Eisenhardt, 1999).

Conclusion

Theoretical contributions from this research were made by extending real options theory to the appropriability framework and external commercialization. However, this study was unable to provide a conclusive response to the original research questions. There was an overall lack of empirical support for the hypothesized relationships between appropriability conditions, external commercialization and firm performance. One reason may be that the boundary conditions are more specific than were examined in this study. The future research recommended here has potential to further drill down on these questions and extend the literature in new and exciting ways.

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