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REAL OPTIONS REASONING AND A NEW LOOK AT THE R&D INVESTMENT STRATEGIES OF PHARMACEUTICAL FIRMS

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Real options reasoning (ROR) is a conceptual approach to strategic investment that takes into account the value of preserving the right to make future choices under uncertain conditions. In this study, we explore firms' motivations to invest in a new option. We find, based on an analysis of a large sample of patents by firms active in the pharmaceutical industry, that their investments in R&D are consistent with the logic of ROR. We identify three constructs—scope of opportunity, prior experience, and competitive effects—which have an influence on firms' propensity to invest in new R&D options and which could usefully be incorporated in a strategic theory of investment.

Strategic management research has long focused on understanding differentials in performance across firms (Helfat, 2000). An important explanation for observed differentials in performance is the ability of firms to introduce innovations that permit them to garner rents. Broadly construed, innovation consists of the development of new products, new processes, and/or new markets (Schumpeter, 1934). The rents attainable through innovative activities are often termed 'Schumpeterian' or 'entrepreneurial' rents, because they are the rewards to firms who are prepared to act in the face of *ex ante* uncertainty (Knight, 1921; Rumelt, 1987). While innumerable empirical studies have linked innovation to superior performance (e.g., Lawless and Anderson, 1996; Christensen, 1997) and many scholars have offered theoretical insights on decision making surrounding innovation within firms (March, 1991; Van de Ven, 1986; Dougherty, 1992), little empirical research integrates normative theories developed largely in finance, and behavioral theories emerging from organizations research regarding the drivers of decisions to invest in innovation.

In this paper, we use real options reasoning (ROR) to bridge these theories, by examining innovation investment decisions that take a firm into new technological areas. We characterize the initial foray into a new technological area as a real option, which creates a somewhat proprietary opportunity for the investing firm to make later decisions, such as to further exploit or to exit the area (Kim and Kogut, 1996). The question we address in this paper is: Why do firms take out real technology options?

A real options perspective offers a complementary approach to normative models of investments under uncertainty borrowed from the field of finance (Fama and French, 1992, 1993, 1995, 1996) and behavioral theories of decision making (March, 1991). Where finance theories are based on assumptions of efficient markets and static equilibrium, ROR presumes information asymmetries,

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path-dependent accumulation processes, and uncertainty (Miller, 1998). As many scholars have observed, assumptions borrowed from the field of finance are often at odds with managerial realities, leading to lack of support for hypothesized relationships and to observed inconsistency in managerial application (Dixit, 1992). Chatterjee, Lubatkin, and Schulze (1999) suggest that a key reason such inconsistencies occur is that the markets in which firms compete 'are not as perfect' as the assumptions underlying models from finance might suggest. Nonetheless, powerful ideas from finance offer an economic rationale for observed managerial behavior.

Kogut (1983, 1991), Bowman and Hurry (1993), and Sanchez (1993) were early advocates of resolving the tension between the rationality of finance-based models and the observations of behavioral researchers through an options lens. As they point out, options reasoning accommodates the value of flexibility, differing resource allocation horizons, the process of retrospective sense making, and path dependence. In this paper, we offer support for an options perspective by showing that the investment strategies of a group of firms—in this case, pharmaceutical firms—are consistent with ROR. By 'real options reasoning,' we mean to imply that decision-makers implicitly (or explicitly) respond to the value of the right to preserve decision rights in the future in their investment choices. We believe that ROR can explain some of the differences between actual managerial investment behavior and theorized investment behavior. Our goal is to advance a theory of investment appropriate to the strategy field.

In short, we seek to explore whether decision-makers in pharmaceutical firms demonstrate ROR in R&D investments. We follow an established body of scholarly work that identifies certain investment decisions as amenable to ROR, then examines evidence for whether actual investment patterns are consistent with the predictions of real options theory. Such analyses have been conducted with respect to joint ventures (Kogut, 1991), international entry decisions (Chi and McGuire, 1996; Reuer and Leiblein, 2000), governance choices in collaboration (Folta, 1998), foreign direct investment decisions (Kogut and Kulatilaka, 1994), and R&D investments (Kumaraswamy, 1996). If we find such evidence, it suggests to us that ROR has much to contribute to a theory of investment in the field of strategy. The research reported here builds upon a growing literature that offers empirical evidence to test propositions originating from ROR (such as Hurry, Miller, and Bowman, 1992; Folta, 1998; and Kumaraswamy, 1996).

We studied patterns of R&D patenting for all participants in the U.S. pharmaceutical industry over a period of 17 years (from 1979 to 1995), with emphasis on the strategies of the leading 31 firms. Our focus was on identifying influences on the decision of firms to invest in growth options. We operationalized the decision to take out options in an R&D arena by measuring patents in pharmaceutical subclasses, on the premise that without investment input the knowledge creation that leads to patenting outputs would be impossible. We believe the study to be timely, for although ROR has attracted considerable scholarly attention, empirical research is still rather sparse.

REAL OPTIONS REASONING AND STRATEGIC INVESTMENTS

In recent research there has been intense interest in understanding how ROR might usefully complement net present value-based approaches to investment decisions (Mitchell and Hamilton, 1988; Nichols, 1994a; McGrath, 1997; Trigeorgis, 1996; see also Bettis and Hitt, 1995). A further incentive is for scholars to develop models that more closely align with managerial practice. Brennan (1995: 17) observed in a retrospective of developments in finance that a general trend in corporate finance is a 'shift away from attempts to *prescribe* normative rules for decision-makers that would assist them to take decisions that are optimal from the point of view of shareholders and towards attempts to *describe* more realistically the way that decisions are actually made' (emphasis in the original).

An option creates value by generating future decision rights. The theory of real options, in which the option in question is a real asset, is derived from theories originally developed in finance to account for the value of financial options contracts (Black and Scholes, 1973). A financial option contract conveys the right, but not the obligation, on the purchaser to either buy or sell an underlying asset at some point in the future. By analogy, an investment in a real option conveys the right, but not the obligation, for a firm to make further investments or defer such investments. Thus, a firm that invests in R&D can create a unit of new knowledge. It can secure its claim to commercialize this knowledge through patenting. Subsequently, it may elect to proceed to extend the knowledge, commercialize its knowledge, to do nothing with it, or to seek to leverage the knowledge in some other way, for example by sharing it with a joint venture partner or licensing it out.

Investing in real options can allow firms access to a greater variety of opportunities than would be possible if each investment represented a full-scale launch. The cost of an option on an asset is small, relative to the cost of purchasing the asset. Thus, with the same resources to spend, more opportunities can be explored using options. Once uncertainty is reduced, an investor can then elect to exercise only those options that are 'in the money' and allow the remainder to expire. By investing relatively small amounts in learning about several promising technical directions simultaneously, a firm can broaden the range of alternatives it can apprehend, generating conceptual variety with parsimony. As Gavetti and Levinthal (2000: 115–116) point out, 'If low-outcome draws can be costlessly discarded, then greater variance in the sample, holding the mean constant, increases the expected value of those draws that are adopted. This is the basic intuition behind the recent interest in the idea of "real options" in the business strategy literature.'

Expanding the number of trials that can be undertaken when uncertainty is high is valuable from a strategic point of view. As Chatterjee *et al.* (1999: 560) point out, 'strategy is about making resource commitments before the relationship between these commitments and their potential performance outcomes are fully understood.' Options, they suggest, are an important mechanism through which firms reduce the strategic risk of making commitments. From their argument, we can identify constructs that are relevant to a strategic theory of investment incorporating ROR. Here, we will focus on variance or scope of the opportunity, portfolio or prior experience effects, and competitive effects in the R&D investment decision. The logic for selecting these constructs is that variance is relevant to the individual investment proposition, portfolio effects to the activities of the firm as a whole, and option expiration to the viability of the underlying asset on which options are taken in future competition. They thus reflect the influence of factors at three levels of analysis relevant to the value of a real option.

Scope of opportunity

Strategic decisions with respect to entry into new markets have at their core firm-specific risk. The core question is whether an investment or entry into a new area has the potential to help a firm protect its future earnings streams from industry and macro-economic pressures reflected in market portfolio returns. If such entry contributes to competitive advantage, investment in the area is valuable, a conclusion that is not controversial (Porter, 1980). However, it is important to consider the scope of opportunity, potential access to other avenues of growth or, in other words, the variance underlying such investments. For financial options, an increase in the scope of the opportunity represented by the volatility of the stock on which an option contract is written leads to an increase in the value of the option. This occurs because the investment in the option is fixed at the price of the option, giving the investor access to a greater range of potential outcomes on the upside, while containing exposure on the downside. This effectively truncates the left-hand tail of a performance distribution, creating a performance distribution curve that is skewed to the right, yielding asymmetric pay-offs. The real options analogue is that provided the downside loss an organization would sustain if it elects to stop further investment in a technology area is contained, its investments *increase* in value with increases in variance of results (Mitchell and Hamilton, 1988). Thus, the presence of potentially high variance in performance outcomes for an investment should be positively associated with investment using ROR, where they might depress the value of an investment using other approaches (Morris, Teisberg, and Kolbe, 1991).

In an argument consistent with this line of thought, Dixit and Pindyck (1994) have suggested that a test for the presence of ROR in R&D strategy is whether those making investment choices favor exploratory research, with a scope well beyond that of current activities. Exploratory research is likely to show the potential for opening up new lines of scientific inquiry in a significant manner, increasing the potential variance of returns. Such increase in scope can potentially lead to a radical departure from prevailing practice. The greater the scope of an opportunity area, the greater is the potential upside of an uncertain investment.

The following hypothesis is consistent with our expectations that the presence of ROR in investment decisions will be reflected in a propensity to engage in more exploratory R&D:

Hypothesis 1: There will be a positive association between a firm's propensity to take out growth options in a new technological area and the scope of the opportunity area.

Prior experience

In large pharmaceutical firms, the R&D function encompasses many projects across many therapeutic and scientific areas. Decisions about making investments in R&D are therefore always made in the context of a portfolio of other, competing investments. As we observed earlier, making investments in options implies that an investor can explore a larger number of possibilities than were each exploratory foray to be a full launch. But does ROR offer any insight into trade-offs decision-makers must make when considering alternative investment proposals?

Conventional investment theory suggests that firms should proceed to invest in all projects with a positive net present value. If resources for investment are limited, as would be the case under capital rationing, the conventional wisdom is to establish a discounted cash flow valuation for each project independently. The next step is to evaluate which combinations of affordable projects would yield the firm the highest total net present value, then invest in this combination of projects. The assumptions underlying this approach are that projects can be evaluated independently, and that their joint effect on future value is largely additive (although correct application of the NPV rule is based on incremental cash flows).

ROR allows instead for an interaction among investments that changes the value not only of a given investment but also of the other options within a firm's R&D portfolio. Because options interact, making a decision with respect to one option affects the value of other options. For instance, subsequent option investments in R&D arenas can increase the value of options opened earlier, because they lead to increase in the value of the underlying knowledge as such knowledge is typically created in a path-dependent cumulative manner (Nelson and Winter, 1982). Lack of continued investment in an arena can also diminish the value of earlier options because this terminates the learning process, effectively extinguishing the earlier option (Dierickx and Cool, 1989; Trigeorgis, 1996: 257–258). Because options within a portfolio may not be additive, and because opening options consumes resources, adding more options to an existing portfolio does not necessarily increase the value of the portfolio. Real options that are compound options often involve nested investments such as entry into new technological areas (Miller and Folta, 2002). For instance, patents in new areas can be considered as compound options that require additional investments before the value of the original option is realized. This is in stark contrast to the net present value approach, which largely assumes independence and additivity for each project.

Present value analysis also does not explicitly recognize the often positive effects on the value of an asset of deferring investment or of the risk of loss of value due to option expiration. As we mentioned, the decision to open or not open an option has value under conditions of uncertainty. The value of waiting, however, is sensitive to the extent to which contingencies are highly uncertain, and the claim of a firm on the underlying real asset can be maintained. As uncertainty is reduced over time, the benefits of waiting relative to investing or abandoning decrease. Trigeorgis (1996: 241), for instance, suggests that the value of the option if not exercised is subject to diminishing returns with the passage of time. This insight has important portfolio implications. For a decision-maker using ROR, the value of a new option will be influenced by the presence of preexisting options. Moreover, its contribution to a firm's existing portfolio of R&D opportunities depends to a large extent on the firm's prior experience and the declining value of waiting to exercise previously created options.

Thus, if a firm has made extensive investments in opening options, its managers should not be anxious to open still more options. Rather, they will be inclined to invest in better understanding those options they have already created, because the value of their option to defer exercise will begin to decline if they do not. Regardless of the inherent attractiveness of a new opportunity, if a firm's resources are already engaged in the pursuit of other attractive opportunities, it is likely to value new ones less. This is consistent with March's

(1991) proposition that firms need to incorporate a balance of exploration and exploitation-oriented investments in their knowledge-creating strategies. We thus suggest that extensive prior commitment is likely to dampen enthusiasm for subsequent investment, as in this hypothesis:

> *Hypothesis 2a: There will be a negative association between firm propensity to take out growth options in new technological areas and the extensiveness of its commitments to new areas in the past.*

A second, portfolio-related characteristic consists of the firm's experience or previous track record of investing in new areas. Strong incentives exist for learners to deepen their understanding of areas in which they have gained initial experience. This is due to increases in absorptive capacity that make the assimilation of each new unit of knowledge easier, faster, and less expensive (Cohen and Levinthal, 1990). Further, self-reinforcing behaviors cause the level of competence with an existing technology to exceed the level of competence a learner could quickly achieve with a new technology, however potentially superior the new one might be (Levitt and March, 1988; Lane and Lubatkin, 1998). With respect to R&D investments, Sørensen and Stuart (2000) find empirical evidence supportive of the idea that as firms age and gain experience with the knowledge generation process they pursue more innovations. Other researchers have suggested that this effect is most pronounced when the new innovations sustain previous technological trajectories for established firms (Christensen, 1997; Henderson and Clark, 1990).

Extending the argument we developed above, a firm that has opened options on an area will have incentives to persist in making investments in that area. Because the value of an option is subject to diminishing returns, a firm cannot indefinitely put off making a decision with respect to the new area without the value of its existing options eroding. Further, the decision to divert resources from an option (once opened) to pursue another opportunity effectively decreases the value of the original option in two ways. First, it truncates the potential of the investing firm to idiosyncratically reduce uncertainty and claim an underlying asset for itself. Second, the decision to divert resources implies that the routines accumulated to date in exploring the option will be forgotten, essentially leading the option to expire. The effect is to diminish the firm's incentive to invest in attractive new areas because it is already committed to areas it had previously explored. We can state this argument as a hypothesis:

> *Hypothesis 2b: There will be a negative association between a firm's propensity to take out growth options in a new technological area and its cumulative investment experience in previous technological areas.*

Competition

The third construct we consider in our exploration of ROR concerns the effects of competition on a firm's propensity to invest in new options. Attractive opportunities tend to attract competition. This creates a tension for the decision-maker. On the one hand, options on more attractive spaces are likely to be more valuable while, on the other, competitors are likely to also perceive the opportunity and seek to take out their own options. Further, a key premise of ROR is that investments are sequential. Failing to take out an investment when others are investing creates the potential for subsequent lock-out.

The use of ROR should be reflected in the way in which this tension is resolved (Dixit, 1992). Decision-makers from different firms are likely to have different expectations with respect to the worth of an emerging arena. The behavior of competing firms is then interpreted as either supporting or disconfirming these expectations. If a decision-maker observes that no other firm is taking out options in an area that he or she has independently concluded is attractive, one reasonable inference is that the judgment was excessively optimistic, which decreases the incentive to invest. If no other organizations take out options, it makes sense to postpone investment. Conversely, let one firm invest and decision-makers from other firms are likely to revise their expectations upward, creating what Dixit (1992: 119) calls a 'bunching' of investment. Investment by one thus provokes investment by many (see also Trigeorgis, 1991).

Because knowledge development is a cumulative process, competitive entry into an area is not only a signal of its attractiveness, but actually does make the arena more valuable by increasing the total investment in knowledge creation across all actors in the area. Hambrick, MacMillan, and Barbosa's (1983) conclusion that total investment matters more than relative investment to technological success is supportive of this argument. When a new technological area is just emerging, it is in the collective interest of all participants to invest to create a substantive body of underlying scientific knowledge, and even to share this knowledge with one another (see McGrath and McGrath, 2001, for a recent review of the issues involved in knowledge spillovers).

Singly and collectively, firm-level investments in R&D thus help to deepen knowledge in a field, reducing uncertainty. Dixit and Pindyck (1994) refer to the taking of such options in uncertain new areas as investments to reduce 'technical uncertainty.' This uncertainty cannot be reduced by postponing investment, unlike uncertainties that might have to do with purely exogenous factors such as the cost of raw materials inputs. High levels of technical uncertainty thus create pressure to invest.[1] We capture this set of arguments in the following hypothesis:

> *Hypothesis 3: There will be a positive association between firm propensity to take out growth options in new technological areas and competition in those areas.*

RESEARCH METHODS

Research setting: The pharmaceutical industry

Investment in pharmaceutical R&D has often been characterized in the literature as investment in the creation of real options (Dixit and Pindyck, 1994; Trigeorgis, 1996: 1–30; Mitchell and Hamilton, 1988; McGrath, 1997). Indeed, it is precisely the uncertainty, long time horizons and asymmetric pay-off distributions to investments in R&D that have prompted considerable scholarly and practical interest in furthering the development of real options theory for pharmaceutical R&D (for instance, at Merck; Nichols, 1994b).

The pharmaceutical industry is attractive as a setting in which to test ideas about ROR. R&D investment in pharmaceuticals can be assessed by reference to published patents. Patents are an important source of technological advantage in general but more specifically in the pharmaceutical industry (Levin *et al.*, 1987), with the consequence that it is a reasonable assumption on our part that investment in an area is reflected by the patents granted to a firm in that area. Successful patenting is a precursor to product development in pharmaceuticals. The upside of a successful discovery that becomes a new drug is assured, to some extent, by the intellectual property protections in the patent. We use patent data to assess the propensity to make R&D investments by firms, consistent with the research efforts of other scholars who have used patents to measure R&D knowledge (Ahuja, 2000; Silverman, 1999; Dutta and Weiss, 1997; Henderson and Cockburn, 1994; Jaffe, Trajtenberg and Henderson, 1993; Engelsman and van Raan, 1994).

There is considerable precedent for our treatment of patents as real options. Pakes (1986), for instance, uses option valuation to assess the propensity of patent holders to exercise or allow their patents to expire. Patents align with the criteria for a real option. Because the pay-off to later commercialization is uncertain, their performance distribution is unknown. Because taking out a patent does not commit the firm to follow-on commercialization, a firm can control the potential downside loss and make sequential decisions, creating the asymmetric distribution of potential returns that is characteristic of real options. In short, a patent confers on the firm the right but not the obligation to make further investments, culminating in a decision whether to commercialize its knowledge or not. Investments made towards commercializing the knowledge underlying the patent are analogous to the exercise price on the real option.

Operationalizing options in R&D investment decisions

A core issue for our empirical research is distinguishing among those decisions that might result from random chance or luck and those that result from strategic decision making (Alchian, 1950; Barney, 1986). We have operationalized investment in an option as the granting of a *second* patent to a firm in a technological area that was previously new to it. One could argue that obtaining a first patent in a new area could arise

[1] Increasing competition typically leads to decreases in profit potential in the context of product markets (Porter, 1980) but not necessarily in technology markets (Arora, Fosfuri, and Gambardella, 2001). In such cases, using real options as a preemptive mechanism might be a useful strategy. See Miller and Folta (2002) for a detailed exposition of these and related issues.

because of luck. The patent might simply be a product of the uncertain stochastic processes that underlie success and failure in R&D (Levinthal, 1990; Nelson and Winter, 1982). Irrespective of whether taking out a first patent can be viewed as an option or not, a second patent in a new area is prime evidence of the initiation of a pattern of investment in that area, indicates a firm-level commitment to that area and is a much stronger indicator of a deliberate choice to focus there than a first patent.

We collected data for the period 1971–95, but we used only the data in our sample from 1979 to 1995, a period of 17 years, to test our hypotheses. The data we collected from 1971 to 1979 were used to help alleviate the problem of left censoring by ensuring that we did not systematically omit patents whose precursor investment took place before our period of observation began, or count third patents as second patents because a first patent was granted in the period before our observation period began.

We defined a technological area in a way that is consistent with U.S. Patent Office Classifications and earlier research (Shane, 2001; Ahuja, 2000; Rosenkopf and Nerkar, 2001). Each patent contains extensive information about the inventor, the company to which the patent is assigned, the technological antecedents of the invention in the form of other patents that it cites, and the claims each patent proposes for its technical contribution. The above information can be accessed in computerized form. Every patent is assigned to a three-digit technical class. Within each three-digit class there are many subclasses. In this study, we define a technical area as the three-digit subclass within the 514 area (i.e., drugs and bio-affecting compositions) as the pharmaceutical class (Penner-Hahn, 1998).

The unit of analysis is the individual patent and its associated content, and the level of the analysis is the firm. We consider only patents filed in the United States. The sources for this information include the U.S. Patent and Trademark Examiners Office and online databases such as Lexis-Nexis® and Derwent®.

Focal organizations

Our research question relates to the strategic choices made by firms. In the pharmaceutical industry, 31 firms account for 80 percent of all drug development and patenting in the pharmaceutical sector. The remaining actors include smaller start-up organizations, universities, independent researchers, and a variety of other firms (for instance, those not competing in pharmaceuticals at all). For purposes of our study, the investment decisions of greatest interest are those involving the 31 major players in pharmaceuticals. The data set on which we test our hypotheses consists of 45,757 patents established by these 31 firms from the 17-year period from 1979 to 1995. Each of the 31 firms lists as their primary Standard Industrial Classification (SIC) code Number 2834 (pharmaceutical) and each had at least 100 patents granted to them during the time frame of the study. By examining these firms, we capture the majority of activity taking place in the pharmaceutical sector.

The results of our analysis may not generalize across smaller firms with fewer than 100 patents. It is important for the reader to realize this, because smaller firms are regarded as likely to undertake more exploratory forays in the development of new technical knowledge, have fewer resources, and are apt to be more limited in the extent to which they open new options. During the period of the study, based on the 47,757 patents, the firms in our sample took out 7654 first patents and 4013 second patents in the same technical area (patent subclass). Our sample of options thus consists of 4013 observations of second patents in technological areas new to the firms taking out the patents. A sample data point is shown in Figure 1.

Dependent variable

The dependent variable for this study is the propensity of a firm to take out a new option, which is operationalized as the instantaneous probability or hazard rate of taking out a second patent in a patent subclass that is new to the firm (i.e., it has only one previous patent in a pharmaceutical subclass that it had not patented in before).

Independent variables

Scope of opportunity

The scope of an investment in a second patent is measured by the potential of the opportunity presented by the first patent for a firm. The greater

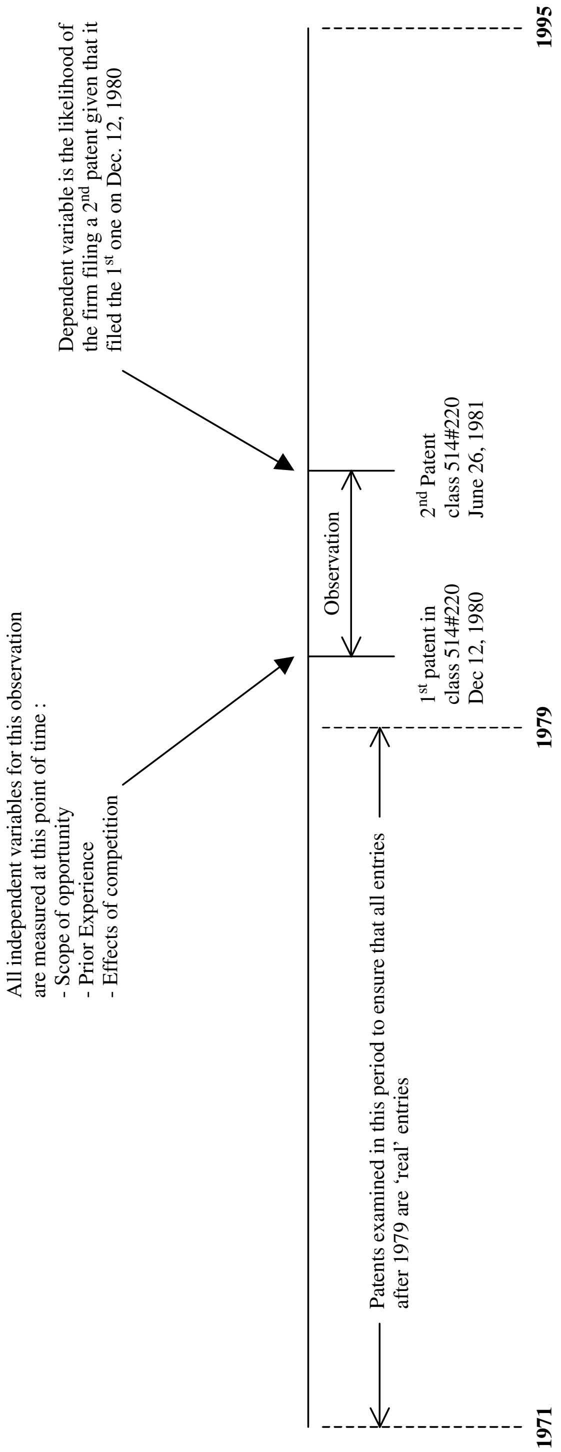

Figure 1. Illustrative data point

its scope, the more likely that it has applications in multiple technological areas. We use two measures of scope: claims made in the patent and overall potential.

Number of claims. While the number of classes indicates the categorization of knowledge within the patent into different areas, the entire patent is constructed around the claims it makes (Tong and Frame, 1994). A claim is the actual contribution made by the invention. For instance, a patent filed by a firm with respect to a cure for arthritis might have two claims. The first one deals with the compound, while the second describes the manner in which it is administered. Firms are only allowed to file claims that are considered nontrivial and nonobvious by the patent examiner. In addition to potential within and outside pharmaceuticals, the number of claims made by a patent indicates the areas of impact. More claims increase the potential application areas for a patent (Lanjouw and Schankerman, 1999), increasing variance in performance outcomes and hence the option value of pursuing a second patent. To measure breadth of potential impact we measured the number of claims granted in the first patent.

Overall potential. Following Lerner (1995), Rosenkopf and Nerkar (2001), and Shane (2001), who suggest that patents classified in more technological areas are broader in scope, we operationalized the scope of a patent by measuring the number of technological classes into which it is categorized.

Prior experience

Extensiveness of previous commitments was measured by counting the cumulative number of new areas entered by the firm. First we determined the total number of all new technical areas (new subclasses) that the firm has entered in the past, measured at the time that the first patent in the current new technical area was granted. The more options it has taken out in the past, the more the firm needs to be concerned with expiration of those options.

Cumulative investment experience: here we used two measures.

Pharmaceutical patents. This is the cumulative number of patents the firm has been granted in the pharmaceutical sector, calculated at the time when the first patent in a new technical area was granted. This is a measure of the degree to which the firm may be concerned with exploitation of existing options.

Non-pharmaceutical patents. This is measured as the cumulative number of patents that the firm has been granted in other sectors, calculated at the time when the first patent in a new technical area was granted. This is another, even broader measure of the degree to which the firm may be concerned with the exploitation of existing options.

Effects of competition

We used two measures for effect of competition.

Competitor commitment. This is measured as the average number of patents granted per competitor in the new technical area for the firm, measured at the time the first patent was granted to the firm in that new technical area.[2] Very low commitment by competitors indicates limited opportunity for firms seeking patents, signaling a sparse environment unattractive to potential new entrants. A large number of patents per competitor signals a hotly contested environment, also unattractive to new entrants.

Number of competitors. This is measured as the number of competitors in the technical area at the time the first patent in the new technical area was granted to the firm. Competitors were defined as any other organization with patents in the technical area of concern. This might include not-for-profit organizations (such as universities).

Figure 2 depicts the operationalization of our theoretical model developed in Hypotheses 1, 2a, 2b, and 3.

Analytical techniques

Following Podolny and Stuart (1995) and Podolny, Stuart, and Hannan (1996) we use event history

[2] We also ran regression models with number of patents instead of patents per competitor and the results were similar. However, we prefer using patents per competitor as the number of patents is highly correlated with number of competitors.

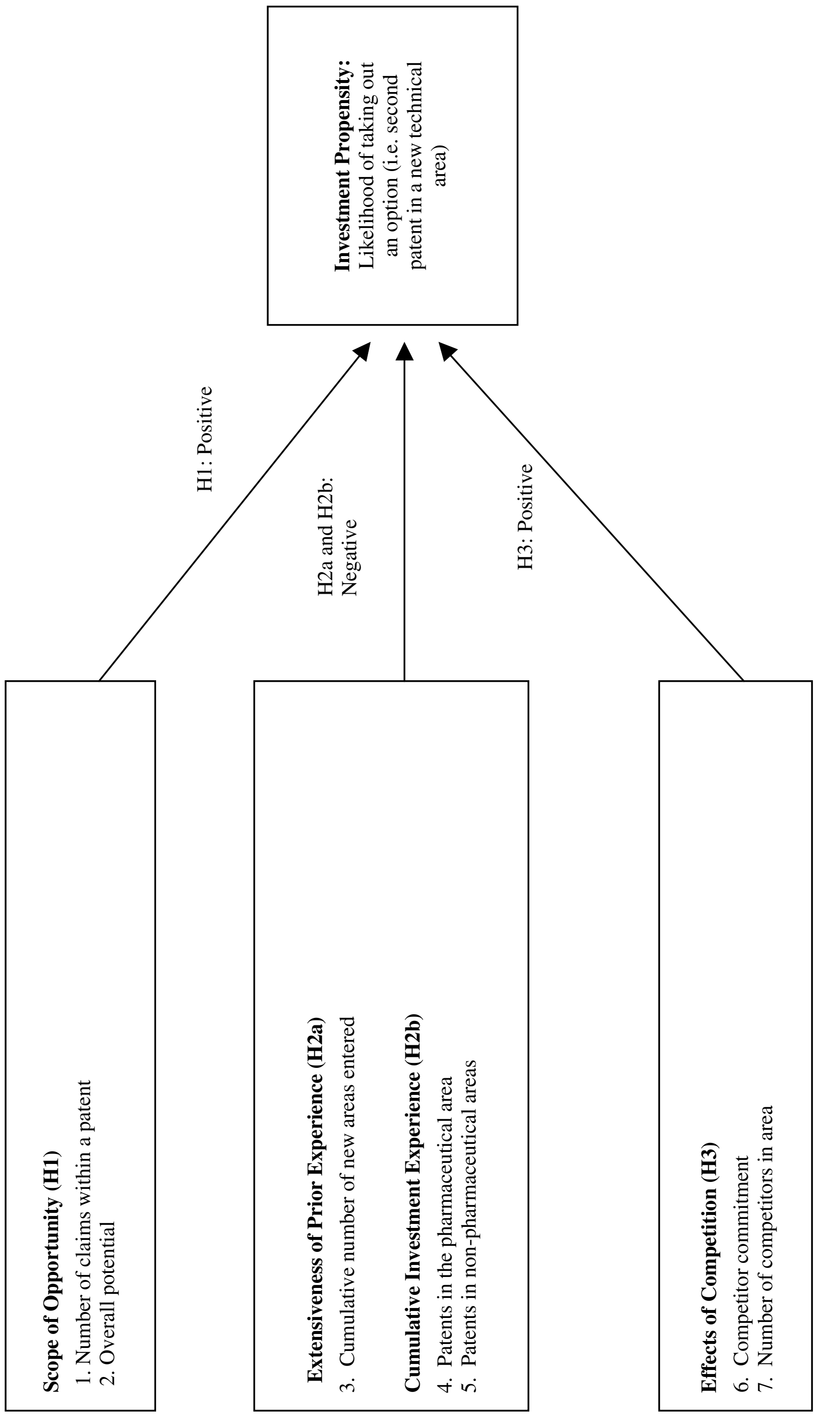

Figure 2. Constructs and measures

analysis to model investment behavior. Hazard rate models are used as they incorporate information on both censored and uncensored cases, i.e., whether a firm files a second patent in the area. If T is the duration since the first patent was granted, then the instantaneous (hazard) rate of a second patent being filed at time t is defined as

$$r(t) = \lim_{\Delta t \to 0} \frac{\Pr(t \leq T < t + \Delta t)}{\Delta t}$$

We modeled the hazard rate using semiparametric Cox models (Cox, 1972; Kalbfleisch and Prentice, 1980; Allison, 1995). The equation that we estimate takes the following specification:

$$r(t) = h(t)\ \exp\{X\beta\}$$

where $r(t)$ is the transition rate or hazard rate of a second patent being filed after the grant of the first patent, $h(t)$ is an unspecified baseline rate for the transition, X is a matrix of time-constant covariates and β is a vector of unknown regression parameter. Because $h(t)$ is an unspecified step function, the Cox model offers an extremely flexible means for modeling time dependence (Sørensen and Stuart, 2000). In this case X consists of the set of controls and the independent variables.

The models also include dummy variables to control for fixed firm and year effects that account for factors inside the firm and time-changing factors that may have affected the pharmaceutical industry. These dummy variables control for omitted variables that may have constant effects on the firms in the sample but vary over time. Our analysis also includes the number of options taken out in the past (second patents in new areas) as an explanatory variable. By including the number of times the dependent variable has previously occurred for each firm we control for unobserved heterogeneity (Heckman and Borjas, 1980). As Stuart (2000) indicates, by including such variables we can control for the time constant effects of unobserved factors that produce variance in firms' abilities or dispositions to patent in new areas.

RESULTS

Table 1 provides information on the patenting activity of the 31 focal firms included in the sample. Table 2 presents simple statistics and a partial correlation matrix for the 31 organizations included in the sample.

Table 1. Statistics for firms in sample: 1979–95

Firm name	Censored[a]	Entries	Total
Abbott Laboratories	121	86	207
American Cyanamid	155	138	293
Allergan	106	77	183
American Home Products	115	66	181
Alza	52	16	68
Bristol Myers Squibb	129	199	328
Boehringer Mannheim	108	153	261
Ciba Geigy	134	169	303
Roussel	130	193	323
Sanofi	122	98	220
Fujisawa	127	135	262
Glaxo	111	136	247
Hoechst	131	125	256
Janssen	54	79	133
Eli Lilly	140	154	294
Merck	132	217	349
Monsanto	82	30	112
Pfizer	102	173	275
Pharmacia	68	23	91
Upjohn	114	52	166
Roche	150	197	347
Rhone Poulenc Rorer	135	195	330
SmithKline Beecham	108	131	239
Sandoz	135	109	244
Searle	127	178	305
Schering Plough	130	238	368
Syntex	90	115	205
Wellcome Laboratories	135	88	223
Warner Lambert	176	239	415
Yamanouchi	89	55	144
Zeneca	133	149	282
Total	3641	4013	7654

[a] Censored entries are first patents that did not lead to second patents by the focal firm during the observation period 1979–95.

Table 3 presents the results of the proportional hazards Cox regression of the likelihood of taking out a successful second patent in a new area. The first column reports the baseline log likelihood of such an event. The second column reports the log likelihood with firm and year fixed effects included. These effects are significant in all the models that we analyzed. To test for the independent effects of each of the constructs, we include the variables measuring each construct separately to the baseline fixed effects specification in Models 1 through 4 in Table 3.

Model 1 includes the variables measuring the attractiveness of the opportunity, i.e., overall

Table 2. Simple statistics and partial correlation matrix

Variable	N	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)
(1) Number of Claims	7654	15.647	14.181	1	237	1.000					
(2) Overall Potential	7654	1.683	1.440	0	9	0.169***	1.000				
(3) Number of Areas Entered	7654	166.886	95.442	1	425.5	−0.019*	−0.018	1.000			
(4) Pharmaceutical Patents	7654	395.825	307.461	6	2256	−0.040***	−0.019*	0.524***	1.000		
(5) Non Pharmaceutical Patents	7654	954.721	1092	28	7192	0.035***	0.021**	0.096***	0.387***	1.000	
(6) Competitor Commitment	7654	1.861	0.717	1	8.556	0.024**	0.034***	−0.048***	−0.043***	−0.054***	1.000
(7) Number of Competitors	7654	36.671	30.210	1	284	−0.002	0.030***	−0.063***	−0.067***	−0.048***	0.544***

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3. Proportional hazards Cox regression models of likelihood of opening an option (2nd patent in new area)

Variable description	Baseline	Fixed effects	Model 1	Model 2	Model 3	Model 4	Model 5
Scope of opportunity							
Number of Claims			0.0040***				0.0037***
			(0.0010)				(0.0010)
Overall Potential			0.0386***				0.0339***
			(0.0109)				(0.0110)
Extensiveness of prior experience							
Number of Areas Entered				−0.0035***			−0.0026***
				(0.0007)			(0.0008)
Cumulative prior investment							
Pharmaceutical Patents					−0.0007***		0.0000
					(0.0002)		(0.0002)
Non-Pharmaceutical Patents					−0.0001*		−0.0001*
					(0.0001)		(0.0001)
Effects of competition							
Competitor commitment						0.2141***	0.2033***
						(0.0232)	(0.0234)
Number of Competitors						0.0063***	0.0062***
						(0.0007)	(0.0007)
Firm effects (omitted firm—Zeneca)		Significant	Significant	Significant	Significant	Significant	Significant
Year effects (omitted year—1995)		Significant	Significant	Significant	Significant	Significant	Significant
N		7654	7654	7654	7654	7654	7654
Censored		3641	3641	3641	3641	3641	3641
Events		4013	4013	4013	4013	4013	4013
Degrees of freedom		46	48	47	48	48	53
−2 log likelihood	67624.52	67221.54	67190.40	67192.67	67201.59	66938.46	66890.88
Improvement In log likelihood		403.01***	31.14***	29.14***	19.95***	283.08***	330.66***
Comparison		Baseline	Fixed eff.	Fixed eff.	Fixed eff.	Fixed eff.	Fixed eff.

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Values in parentheses are standard errors.

potential and number of claims. The increase in log likelihood is statistically significant as compared to the model that included only the firm and year fixed effects. Also, the parameter estimates of both these variables are positive and statistically significant, offering strong support for Hypothesis 1. These results are consistent with ROR as there is an increasing propensity to take out a second patent, or real option, with corresponding increases in potential and claims.

Model 2 includes only the variable for cumulative number of areas as a measure for the extensiveness of prior experience. This variable is negative, statistically significant, and in the hypothesized direction, offering support for Hypothesis 2a. The improvement in log likelihood as compared to the baseline model with fixed effects is also significant. A similar result supporting Hypothesis 2b is seen in Model 3, where only variables measuring cumulative prior investments are included. These results generally support the argument that the R&D investment decisions of the firm will be influenced by past option investment decisions, rather than showing no impact from previous investments, as the net present value model might suppose.

The independent effects of competition are tested for by including the two variables of competitor commitment and number of competitors in Model 4. Both these variables are positive, statistically significant, and in the hypothesized direction. The improvement in log likelihood over the baseline fixed effects model is statistically significant. The results of Model 4 generally support the ROR argument that the R&D option decisions of the firm will be influenced by the signals of option potential emanating from the activities of competition. The pattern of our results suggests that both the number of competitors and their patenting record will have a positive effect on a firm's propensity to take out an option.

Model 5 is the full model and a complete specification that includes all variables measuring the different constructs described in the different hypotheses. All the independent effects except those represented by the variable measuring cumulative prior investments continue to be significant in this model, offering strong support for Hypotheses 1, 2a, and 3, and partial support for Hypothesis 2b.

Comparing the results across the four sets of constructs from Model 5 offers some insight into their relative strengths in terms of their impact on likelihood of taking out an option. An increase of 10 percent in the overall potential measure from its mean level leads to a 6.48 percent increase in the hazard of taking out an option[3] ($\exp[0.034 \times 1.8515] = 1.0648$). In contrast, an increase of 10 percent in the mean commitment exhibited by competitors leads to an increase of 51.6 percent in the hazard of taking out an option ($\exp[0.2033 \times 2.047] = 0.1516$). The corresponding percentage increase or decrease in the hazard of taking out a second patent with 10 percent increase in mean value of the various constructs is as follows: claims (6.56), cumulative areas entered (37.9), pharmaceutical patents is (-1.72), non-pharmaceutical patents is (-9.48) and number of competitors (28.31). In other words, the effect of the average commitment exhibited by competitors is nearly eight times the magnitude of the effect of the average potential exhibited by the opportunity area. The above comparison also suggests that competitive effects have the greatest influence on the likelihood of taking out an option, followed by prior options taken out and the scope of the opportunity. These differences in magnitude are consistent with research that technical attractiveness is not the only variable that drives entry decisions (Podolny and Stuart, 1995).

Effects of competition: Testing for curvilinear effects

As uncertainty is reduced, however, the value of options decreases, and the potential value of the underlying knowledge asset becomes easier to assess. The implication is that, in the early stage of a new technological arena, the more competitors take out options, the greater will be the incentive for additional firms to take out options. As the area matures, however, continued investment will only be attractive for those firms who perceive that they will be in a good position to exercise their options. For the rest, allowing their options to expire (or

[3] To examine the multiplier effect of each variable on the hazard rate, keeping all other variables at their mean, one needs to compute the exponential function of the product of the new value of the focal variable and its parameter estimate. For instance, in our case the 10 percent increase in mean value of overall potential leads to a value of 1.8515. On taking the exponential function of this value multiplied by the parameter estimate (0.34) we get the increase in the hazard rate, i.e., 1.0648. For a more detailed explanation of how multiplier rates are computed see appendix B of Haveman and Cohen (1994).

Table 4. Proportional hazard Cox regression models of likelihood of opening an option: testing for curvilinear competition effects

Variable description	Model 6	Model 7	Model 8
Scope of opportunity			
Number of Claims	0.0036***	0.0038***	0.0037***
	(0.0010)	(0.0010)	(0.0010)
Overall Potential	0.0333***	0.0332***	0.0329***
	(0.0110)	(0.0110)	(0.0110)
Extensiveness of prior experience			
Number of Areas Entered	−0.0026***	−0.0025***	−0.0025***
	(0.0008)	(0.0008)	(0.0008)
Cumulative prior investment			
Pharmaceutical Patents	−0.0001	−0.0001	−0.0001
	(0.0002)	(0.0002)	(0.0002)
Non-Pharmaceutical Patents	−0.0001**	−0.0001**	−0.0001**
	(0.0001)	(0.0001)	(0.0001)
Effects of competition			
Competitor commitment	0.5397***	0.1836***	0.4455***
	(0.0839)	(0.0242)	(0.0859)
Competitor Commitment^2	−0.0606***		−0.0461***
	(0.0152)		(0.0151)
Number of Competitors	0.0052***	0.0116***	0.0096***
	(0.0007)	(0.0015)	(0.0016)
Number of Competitors^2/1000		−0.0408***	−0.0315***
		(0.0102)	(0.0102)
Firm effects (omitted firm—Zeneca)	Significant	Significant	Significant
Year effects (omitted year—1995)	Significant	Significant	Significant
N	7654	7654	7654
Censored	3641	3641	3641
Events	4013	4013	4013
Degrees of freedom	54	54	55
−2 log likelihood	66870.67	66870.87	66859.56
Improvement over full Model 6	20.20***	19.99***	31.31***
Chi square	753.86***	753.66***	764.97***

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

trading them with one of the more advantaged firms) makes more sense. The options story is thus not so much about competition creating resource pressure upon rivals (as in the ecological literature) but rather about strategic redirection of effort, based on the joint effects of uncertainty reduction and the potential of heterogeneous resource combinations. Both the positive effects of collaboration and positive spillovers from competitors doing R&D and the negative effects of rivalry amongst competition are possible on likelihood of entry. Thus the curvilinear results for competition are worth further exploration. To do this we analyzed three models, shown in Table 4, where we include the squared terms of the variables measuring effects of competition.

Models 6 and 7 show support for the independent curvilinear effects of competitor commitment and number of competitors respectively. Model 8 includes both curvilinear effects and the results continue to support a curvilinear relationship between the likelihood of taking out an option and competition. To find the point at which the impact of number of competitors on the hazard of taking an option is at a maximum, we differentiate the results for Model 8 with respect to number of competitors, and set the result equal to zero:[4]

$$\text{This gives: } 0.0096 - 2 \times (0.0315) \times \text{number of competitors}/1000 = 0$$

Solving gives the number of competitors as 152.6. This suggests that the deterrent effects of excessive

[4] In the absence of curvilinear effect of competitor commitment the number of competitors at which the hazard is at a maximum is 142.15.

competition on a firm's propensity to invest are at their maximum when 152 competitors have entered the area. Only after as many as 152 competitors are in the market do firms actually find the competitiveness discouraging, but the evidence of curvilinearity suggests a negative marginal effect. The positive effect of increase in competition begins to tail off as the number of competitors increases. Examination of the basic statistics in Table 1 suggests that very few of the data points in our sample have a number of competitors exceeding 152 (the mean number of competitors is 36.8 while the standard deviation is 30.28).[5] This result needs to be interpreted with care, as these 152 competitors are not competitors in the product market context but in the resource or R&D market. A brief examination of a few entries in our data set suggests that early entrants in new areas are universities, research organizations, and independent inventors who are less likely to be interested in the commercial aspects of the knowledge they generate. Future research could examine the nature of competition in R&D markets to explore whether signals from entry of different competitors are equal.

To find the point at which the impact of number of patents per competitor on the hazard of taking an option is at a maximum we differentiate the results for Model 8 with respect to competitor commitment, and set the result equal to zero:[6]

$$\text{This gives: } 0.4455 - 2 \times 0.0461 \times \text{number of patents} = 0$$

Solving gives the number of patents per competitor as 4.83. This further supports the ROR argument—only after as many as 4.83 patents per competitor do firms reduce their patenting. Again statistics from Table 1 suggest very few cases in our sample have competitor commitment beyond 4.83 (mean is 1.86 and standard deviation is 0.72), but again the evidence of curvilinearity suggests a decreasing positive effect as the number of patents per competitor increases. In both cases the concave function obtained strongly suggests that the rate of increase in the log likelihood of a firm taking out an option goes down with increases in the number of competitors and competitor commitment. Thus firms in our sample are initially increasingly, then decreasingly inclined to take out options in new technical areas as the opportunity space becomes more competitive.

We see that the effect of patent/competitor is much more than that of number of competitors. This is consistent with the argument that competitive entry has an important signaling effect on the propensity to enter. Signs that competitors are making significant headway in the new area, as evidenced by their success at patenting there, however, can be expected to act as a deterrent, consistent with our results.

DISCUSSION AND IMPLICATIONS

Our study of R&D investments in the pharmaceutical industry suggests that strategic decision-makers do either intuitively or explicitly use ROR when making investment choices under uncertainty. We identified three constructs that are derived from ROR but that at present have not been incorporated into a theory of investment for the field of strategy, namely the potential for increased variance, effects of previous portfolio investments, and the tension created by competitive entry.

Rather than being deterred in making investment by their potential variance enhancement, we found that scope (potential of the previous patent in a new area) had a positive effect on firms' propensity to invest in R&D. One implication is that variance, measured as the scope of the opportunity area, rather than being a negative that would require greater risk premiums from investors, is positive when the investment in question is an option. An implication for the strategic theory of investment is that different standards should apply to evaluation for scope-increasing options as opposed to commitments. It may make sense to allocate different resource pools for the different kinds of investments, because different assessment criteria are appropriate and because different discount rates are also appropriate. Such a distinction, based on options logic, was urged by McGrath and MacMillan (2000: 163–196).

A criticism of net present value-based investment models is that they tend to underestimate future cash flows that are generated from opportunities discovered at a later point in time than were obvious at the point of initial investment.

[5] We are thankful to an anonymous reviewer for identifying this pattern in our data.

[6] In the absence of curvilinear effects of number of competitors the competitor commitment at which the hazard rate is maximum is 4.45 patents per competitor.

Scholars have argued that ROR, because it allows for consideration of future opportunities, mitigates undervaluing investments with latent potential. Our findings suggest that decision-makers do appear in practice to take future opportunities into account, at least when they invest in options. Firms were more likely to invest in new options in areas revealed to be radically different in scope. Those options with greater scope are also those which are more likely to lead to potentially valuable future growth opportunities. By implication, the taken-for-granted assumption that variance-enhancing potentially radical opportunities are likely to be unattractive to established firms should be questioned. Established firms are often characterized as risk-averse, rigid and resistant to change. Our study suggests that investing in change through an options lens may offer a path to greater innovation, mitigating organizational rigidity.

We also found evidence that decisions to invest in new options were influenced by the state of the existing portfolio of options in a firm. The primary implication of this finding is that assessment (and logically, quantitative evaluation) of any single option is interdependent with the rest of the firm's portfolio. Failing to invest in more options in an area diminishes the worth of all previous options in that area because new discoveries with growth potential are less likely.[7] Attractiveness of an established area diminishes a firm's propensity to invest in additional new areas because of diminishing returns to postponement of exercise in the established area. Because of these effects, investing in new options is not necessarily additive. It is conceivable that adding more options to an existing portfolio can actually decrease its value, not increase it as a simple additive model would assume. Thus, in our thinking and modeling we need to go from assumptions of independence and additivity of new investments to assumptions of interdependence and nonlinear effects.

Portfolio effects offer some interesting points of intersection between ROR and theories of organizational learning in strategy. In a highly influential article, March (1991) argued that 'balance' between exploration and exploitation was essential to organizational viability. Our study contributes to the burgeoning literature sparked by March's paper. We found two different mechanisms that appear to influence firm investments in new areas. The scope of a new area triggered an exploratory investment response. In contrast, the successful results of past exploration influenced firms to respond with less exploratory investing, presumably to focus on the learning they had done that was most vulnerable to diminishing returns and eventual erosion. To the extent that previously opened options have not been exercised or allowed to expire, a firm is rational to divert resources from the exploration of new options to concluding its investigations of old ones. Options reasoning thus offers insight into the mechanism through which prescriptions for firms to achieve balance in knowledge creation can be translated to actual strategic decision making.

We also found explanations consistent with ROR in the way in which firms responded to competitive entry. In the early period of discovery of a new technological area, competitive entry induced investment. The observation that competitors have found the arena attractive is likely to lead a decision-maker to adjust expectations for the attractiveness of the area upward as well, making investments in the area more likely. As players enter, all of them benefit from the net investment into the area and the concomitant reduction in technical uncertainty that this produces. With reduction in uncertainty, however, comes evidence of which options will be 'in the money' and which will not. Not all players will be in a position to exercise those options that they have opened. Firms without a potential advantage are then likely to exit as a matter of strategic choice (exercising their option to stop or to redirect). Although this pattern has been identified in previous empirical studies, in which firms have entered, faced stiff competition, and exited from a field (for instance, Sahlman and Stevenson, 1985), this has mostly been examined at the level of a line of business. Researchers focusing on the business level of analysis have thus developed a different rationale for the pattern—namely, entry prompted by high (and often unrealistic) expectations of the carrying capacity of an attractive area, with exit prompted by the inability to sustain the business in the face of competition.

Some important caveats to our conclusions are other explanations that could exist for our results and which should be addressed in future research. For instance, past research has shown that some

[7] However, real options are not additive in nature and the drop due to investment may not be linear.

technologies are more accessible than others, leading to simultaneous inventions by multiple inventors (Merton, 1972). Our data set does not permit us to analyze such effects but future research, by gathering detailed information on the nature of each sub-area, could begin to examine these effects—specifically, the extent to which knowledge in the area is easily articulated, codifiable, and accessible (Winter, 1987) and the extent to which there are network effects on the likelihood of innovation (Powell, Koput, and Smith-Doerr, 1996). For instance, in the business methods area or software arena where knowledge is articulated, codified, and accessible, and where the need for complementary assets such as R&D facilities is minimal, one would expect the likelihood of entry to be driven by the extent to which firms can quickly appropriate rents from such inventions (Bagby, 2000).

Another avenue for research is to develop better measures of value and variability of value from entering a new area. Our measure of the scope of the opportunity, while a reasonable proxy for the underlying variance, is still crude. Future research could develop alternate measures based on licensing or royalty agreements. Finally, we motivate our study by offering a complementary approach to normative investment models borrowed from the finance field. Our intention was to provide evidence that investment strategies of pharmaceutical firms are consistent with ROR. An important topic for future research is to compare the efficacy of these two approaches. Qualitative evidence gathered from our field studies suggests that the real options approach resonates with the thinking of at least a few R&D managers (Nichols, 1994b). However, more rigorous empirical testing of these two approaches in the R&D context is required before further comparisons are made.

ROR, and our study, suggests a different logic for investment within the firm than that reflecting conventional assumptions. Based on this logic, we see entry prompted indeed by expectations for future success. Significant new investment, however, actually does make the area more valuable by leading multiple firms to reduce uncertainty and establish a base of knowledge. Entry eventually slows and ceases, not necessarily as a consequence of resource pressures, but because the area is now revealed to be differentially attractive to different players. Those for whom the upside is no longer substantial stop making further investments in options in it. An implication for scholars is that the concave function that underlies the relationship between competitive entry and propensity to invest has a different causal explanation for options than for businesses (which are by definition more likely to represent commitments, not options). The challenge for researchers is not to stop at identifying the pattern and attributing causality (as is all too often done) but at identifying the logic underlying the pattern.

CONCLUSION

In this research, we explored whether actual firm investment behavior appears consistent with ROR. We thus examined the outcome of firm-level investment decisions in the pharmaceutical sector over a long period of time (17 years). Our findings support the premise that decision-makers either implicitly or explicitly utilize ROR. Our results suggest that the options concept could prove to be a fruitful approach to developing theories of investment in the strategy field that are more consistent with observed managerial behavior than those theories that rely purely on the assumptions of finance or economics. Specifically, we found that decisions to pursue an option on a new technological area (measured by successful second patents filed in those areas) are influenced by the scope of the technological opportunity, the competition in the area, and a firm's past investment behavior. To our knowledge, this is one of the first studies to empirically test the options premise so extensively.

The options approach has implications for improving theories in strategy of how managers matter to the creation of competitive advantage. A core idea in ROR is that of making limited-downside, relatively small investments until sufficient uncertainty has been reduced to make commitments with greater confidence. One effect is to increase the number of areas that can be explored while decreasing the cost of each exploratory foray. Other things being equal, one might therefore expect that under high levels of uncertainty firms managed with an options sensibility have greater internal variety than those that do not, improving their chances for both survival and advantage under rapidly changing external circumstances (Ashby, 1956).

Options reasoning provides an economic rationale for the emergence of performance heterogeneity subsequent to the investment in options. By observing how firms take out options, thus beginning the developmental path for what may turn out to become valuable capabilities, we have specified and measured a point at which management decisions directly influence capability formation. Moreover, options theory offers an economic rationale for this behavior, tying together powerful concepts of future value developed in finance and the observed incremental-investment behavior of firms operating under uncertainty. As organizations seek to cope with ever more rapidly moving competitive environments, creating new capabilities and doing so in a cost-effective way will become a competitive necessity. By examining the process of investing in real options, such as patents in a new pharmaceutical subclass, we provide a point of departure for better understanding resource-based competitive advantages, because at the time of investment the future benefit is not yet known. Thus, the research presented here offers an example of an empirical approach strategy researchers might use to respond to the criticism that the field relies on *post hoc* rationalization (see Cockburn, Henderson, and Stern, 2000).

A further theme that is central to ROR but not yet to our theories of strategic investment is the idea that investments in uncertainty reduction erode in value over time. To use the language of options, they expire. Future research on the erosion of option value and the expiration of real options should test whether firms adopting ROR for investments do let options expire as uncertainty associated with the underlying option is reduced. Further, if existing resource combinations that underlie technology investments become commoditized, and options expire at a rapid rate, firms must be able to rapidly go from exploration of new possibilities to exploiting the commercial potential of those opportunities. In established organizations, such rapid learning and responsiveness is difficult to create as established systems are constructed to yield reliable performance rather than engage in innovative behavior. Our finding of evidence supportive of option expiration, when coupled with the tendency for the products of existing competences and routines to become commoditized, suggests why organizational learning and knowledge management have become a central focus for scholarly attention.

ROR offers a perspective from which to develop ideas that are relevant to the problems facing decision-makers in established firms. We demonstrated that it is possible to derive testable hypotheses grounded in ROR and to collect data that can be used to test the hypotheses. The support for our hypotheses suggests that decision-makers in practice (at least in the U.S. pharmaceutical industry) deploy a pattern of investment choices that is consistent with ROR. As we conclude, it is our hope that real options concepts might offer a useful perspective for those seeking to develop a theory of investment for the field of strategic management.

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