

**Sources and Financial Consequences of Radical Innovation:
Insights from Pharmaceuticals**

Alina B. Sorescu

Rajesh K. Chandy

Jaideep C. Prabhu

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Alina Sorescu is Assistant Professor of Marketing at the Mays Business School, Texas A&M University (email: asorescu@tamu.edu). Rajesh Chandy is Assistant Professor of Marketing at the Carlson School of Management, University of Minnesota (email: rchandy@csom.umn.edu). Jaideep Prabhu is Assistant Professor of Marketing at the Judge Institute of Management, University of Cambridge (email: jcp31@hermes.cam.ac.uk). This research was supported by grants from the Marketing Science Institute, the Mays Business School at Texas A&M University, and the University of Minnesota. The authors thank Ed Blair, Betsy Gelb, George John, Akshay Rao, and Sorin Sorescu, and four anonymous *Journal of Marketing* reviewers for their valuable inputs to this research, and Luis Wasserman and Raghunath Rao for research assistance. They appreciate the comments of participants at seminars at Duke University, Emory University, Ohio State University, Penn State University, University of Houston, University of Georgia, University of Minnesota, University of Pittsburgh, Texas A&M University, and University of Washington.

SOURCES AND FINANCIAL CONSEQUENCES OF RADICAL INNOVATION: INSIGHTS FROM PHARMACEUTICALS

Abstract

Radical innovations are engines of economic growth, and the focus of much academic and practitioner interest. Yet some fundamental questions remain unanswered. We use theoretical arguments on the risk associated with radical innovations, and the resources needed for them, to answer the following questions on the sources and financial consequences of radical innovation:

- Who introduces a larger number of radical innovations: dominant or non-dominant firms?
- How large are the financial rewards to radical innovations, and how do these rewards vary across dominant and non-dominant firms?
- Is it only a firm's resources in the aggregate, or also its focus and leverage of resources that make its innovations more financially valuable?
- Which are more valuable: innovations that incorporate a breakthrough technology, or innovations that provide a substantial increase in customer benefits?

We pool information from a disparate set of sources in the pharmaceutical industry to study these questions. Results indicate that a large majority of radical innovations come from a small minority of firms. The financial rewards of innovation vary dramatically across firms, and are tied closely to their resource base. Firms that provide higher per-product levels of marketing and technology support obtain much higher financial rewards from their radical innovations than other firms. Firms that have greater depth and breadth in their product portfolio also gain more from their radical innovations.

Truly innovative products are important engines of economic growth. Firms ramp up their research budgets in the hope of discovering the next blockbuster product before their competitors do. Financial analysts keep a close eye on firms' product pipelines in the hope of finding the next soaring stock. But who succeeds at the radical innovations game? Which firms introduce these radical innovations and which firms gain most from them?

Questions such as these have inspired generations of writers seeking to document the sources and consequences of radical innovation (Smith and Alexander 1988; Teitelman 1994). Since Schumpeter (1934, 1942) pondered whether small or large firms are the main sources of radical innovations, the debate on the relationship between firm size and innovativeness has grown into the second largest body of literature in industrial organization economics (Cohen 1995). Radical innovation has also been the focus of study in the marketing and management literatures (e.g., Chandy and Tellis 2000; Gatignon and Xuereb 1997; Henderson 1993; Olson, Walker, and Ruekert 1995; Stringer 2000).

Though our knowledge of radical innovation has improved considerably over the last several years, some persistent limitations in the research remain. These limitations are both conceptual and methodological in nature. Conceptual limitations involve the range of questions addressed in the research so far. Methodological limitations involve potential problems in the data and methods used in the research. Our study is motivated by calls to address the methodological issues (Fisher and Temin 1973; Scott 1984), and to explore a hitherto unexplored set of questions regarding the valuation of radical innovations (Wind and Mahajan 1997).

Conceptual Limitations of Past Research: Although research has explored the antecedents of radical innovations, we know virtually nothing about their performance and financial value.

Firms spend billions of R&D dollars trying to create radical innovations. For instance, the cost of developing a blockbuster drug that involves a completely new technology has been estimated to

be between \$250 and \$350 million (Van Arnum 1998). Yet there remain nagging suspicions that the returns to innovation may be scarce (*Fortune* 2000; Golder and Tellis 1993).

All we know so far is that radical innovations are more valuable than incremental ones (Chaney, Devinney, and Winer 1991). But do firms gain more from products that involve a substantially new technology, or from products that respond to an unfulfilled consumer need? Furthermore, do some firms gain more from their products than others? Just as there are reasons why some firms are better at generating radical innovations, there may be reasons why some firms gain more from them. Such reasons – which could include the resources that firms own, and the ability to protect and leverage their new products – have been unexplored so far.

Methodological Limitations of Past Research: One of the thorniest problems in the study of radical innovation is also one of the most fundamental: how to determine whether an innovation is truly radical? Research has used one of two methods to assess radical innovation: surveys and retrospective coding. Researchers using the survey method typically provide respondents with a definition of radical innovation and ask them for an evaluation of the extent to which their firm is radically innovative (e.g., Chandy and Tellis 1998; Ettlie and Rubinstein 1987; Gatignon and Xuereb 1997). Thus, survey-based studies essentially end with the managers' word on whether their firm has introduced or will introduce radical innovations. This type of data could therefore potentially suffer from self-report bias in measuring innovation (Price and Mueller 1986).

Innovation is a desirable outcome and managers may, consciously or unconsciously, feel the need to appear more innovative than they really are. This need not be a problem if all managers are equally prone to this bias and the research questions simply involve comparisons across firms. However, there may be reason to believe that responses from some firms (e.g., those for whom innovation is an explicit corporate goal) could be more prone to this bias than others.

A different kind of bias can arise when retrospective coding is used to assess the radicalness of the innovation: memory and retrospection bias (Golden 1992; Golder and Tellis 1993). Researchers using retrospective coding typically provide a panel of experts a definition of radical innovation and a sample of products introduced at varying points in time, and then ask the panel for an evaluation of the extent to which each product is radically innovative (e.g., Blundell, Griffith, and Van Reenen 1999; Pavitt, Robson, and Townsend 1987). But products that failed may have faded from memory, or their failure may bias the way in which the coders evaluate their innovativeness (e.g., Louie, Curren, and Harich 2000). Alternatively, radical innovations that have been widely adopted and are an integral part of the current commercial landscape may be taken for granted, and may not be perceived as being as radical as they truly were upon introduction. For example, the sewing machine seems like a prosaic piece of household machinery today. However, in 1841, when Barthelemy Thimmonier first introduced the machine, it was a revolutionary product (Cook 1922; Cooper 1976). Parisian tailors, upon hearing of the machine, were so threatened by it that they burned the army tailoring shop where 80 of the machines were first installed. Thimmonier himself barely escaped with his life (Cooper 1976).

This research seeks to address the conceptual and methodological limitations outlined above. We study a broad array of research questions using a unique dataset from the pharmaceutical industry, spanning a ten-year period: 1991-2000. Pharmaceuticals is a knowledge-intensive industry; moreover, innovation is its lifeblood (Gambardella 1995; Scherer 2000). In these respects, it is similar to other important industries - such as consumer electronics, fiber optics, and semiconductor manufacturing - that are commonly studied in the context of innovation (e.g., Chandy and Tellis 2000; Dekimpe and Hanssens 1999; Dutta, Narasimhan, and Rajiv 1999). Findings from pharmaceuticals may have implications for other knowledge-

intensive and innovation-based industries (see Blundell, Griffith, and Van Reenen 1999).

Moreover, pharmaceuticals provide a rich source of data – data that does not suffer from self-report and retrospective coding concerns, and data that permits the study of hitherto understudied research questions.

This paper addresses the following questions on the sources and financial consequences of radical innovation:

- Who introduces a larger number of radical innovations: dominant or non-dominant firms?
- How large are the financial rewards to radical innovations, and how do these rewards vary across dominant and non-dominant firms?
- Is it only a firm's resources in the aggregate, or also its focus and leverage of resources that make its innovations more financially valuable?
- Which are more valuable: innovations that incorporate a breakthrough technology, or innovations that provide a substantial increase in customer benefits?

To address these questions, and to link the two issues of the sources and financial consequences of radical innovation, we develop a single theoretical framework centered on the concepts of *risk* and *resources*. We differentiate between three types of innovations—market breakthroughs, technological breakthroughs and radical innovations. We measure financial consequences by examining how stock market returns vary across firms and across innovations.

By using stock market measures we seek to contribute to the recent stream of research on the marketing-finance interface. Srivastava, Shervani, and Fahey (1998, p.2) note that:

“marketers [can no longer] afford to rely on the traditional assumption that positive product-market results will translate automatically into the best financial results”. By adopting a forward-looking, stock market measure of the financial impact of radical innovations, we respond to recent calls to adopt performance metrics that can be directly related to shareholder value (e.g., Day and Fahey 1988; Srivastava, Shervani, and Fahey 1999). Our stock market measure, as we discuss in the method section, also has considerable managerial significance, thus increasing the relevance of our findings.

Theory and Hypotheses

Definitions

Radical innovations. In a recent paper, Chandy and Tellis (1998) review the literature on radical innovation and note that two common dimensions underlie most definitions of the construct. These dimensions are: 1) the extent to which the product incorporates a new technology and 2) the extent to which it fulfills key customer needs better than existing products. They then propose a taxonomy that differentiates innovations along these two dimensions (Table 1). According to this taxonomy, a *radical innovation* is a product that is high on both the technology and the market dimension: it involves a substantially different technology, while at the same time offering a substantial increase in customer benefits. A *market breakthrough* provides substantially higher benefits than existing products, but its core technology is not significantly new. A *technological breakthrough* uses a substantially different technology than existing products, but without considerably increasing the benefits to consumers. We adopt Chandy and Tellis' taxonomy of innovations along the technology and market dimensions; this taxonomy is consistent with many other definitions of the "newness" of an innovation (cf. Garcia and Calantone 2002). We conduct our study in a context that allows us to empirically differentiate among all three types of breakthroughs.

Dominance. We define dominance as the level of market power wielded by a firm (e.g., Scherer 1980). Authors have traditionally equated dominance with *market share* (see Szymanski, Bharadwaj, and Varadarajan 1993). Some recent authors, however, have noted that there is more to dominance than a firm's share of sales in a particular market (e.g., Borenstein 1990, 1991; Pleatsikas and Teece 2001). This broadened view of dominance incorporates three dimensions: 1) market share, which reflects the revenues from the firm's current position in the market, 2) assets, which reflect the tangible and intangible factors that the firm can bring to bear on the

market (Borenstein 1990), and 3) profits, which reflect the financial resources the firm can bring to bear on the market (Borenstein 1991). Our definition and measures incorporate this more recent, multidimensional view of dominance, as each of the three dimensions could independently influence the resources that a firm brings to its innovation activity. Thus, market share could provide firms with brand equity that they can leverage to stimulate adoption of their innovations, while profits could ensure that they have adequate financial resources to develop and support innovations. Because firms may vary in the extent to which they dominate on each of these dimensions and because these dimensions may bring differing benefits, it is necessary to account for firms' dominance on all three dimensions taken together (e.g., Pleatsikas and Teece 2001).

Financial value. We assess the financial value of radical innovations using the concept of the *net present value* of the future cash flows expected from the innovation (Ross, Westerfield, and Jaffe 1999). Net present value (NPV) is a fundamental criterion for appraising investment projects, and has been widely used by academics and practitioners (Fisher 1965; Ross, Westerfield, and Jaffe 1999). By definition the NPV captures, in our context, the expected value of all future discounted cash flows generated by an innovation. It is, therefore, a forward-looking measure of the overall value of an innovation as reflected in the stock market's expectation of the success of the product and the level of profits it will generate.

Product support and product scope. In addition to dominance, we also examine whether firms' focus and leverage of resources make their innovations more financially valuable. We use two concepts to capture firms' focus and leverage of resources: product support and product scope. We define *product support* as the firm's marketing and technology expenses *per product*. Marketing and technology resources have been frequently linked, often in conjunction, to the success of new products (e.g., Cooper and Kleinschmidt 1987; Moorman and Slotegraaf 1999;

Song and Parry 1997). Product support reflects a firm's ability to protect and support an innovation on the market. We define *product scope* as the extent of a firm's product portfolio within an industry. Product scope encapsulates both the breadth and depth of the product portfolio, and as such reflects the leveraging opportunities of the radical innovation within the firm.

Theoretical Framework

We organize our theoretical arguments around two fundamental concepts: *risk and resources*. Risk refers to the uncertainty associated with a course of action (e.g., Singh 1986). A product is therefore deemed risky if there is high uncertainty associated with its outcomes. There may be a higher risk associated with a radical innovation than with an incremental product (see Golder and Tellis 1993; Robinson and Min 2002; also see Kleinschmidt and Cooper 1991 for a different view) and this risk is apparent at two stages.

First, at the development stage there is uncertainty associated with when and whether a process directed at creating breakthroughs will materialize into actual, ready-for-market innovations. Firms can encourage cutting edge research by dedicating sizeable resources to R&D, but they cannot command or even predict the moment when a scientist's mind will go beyond the frontier of existing knowledge. Second, at the introduction stage, there is uncertainty associated with the extent and time frame over which consumers will adopt the product (Griffin 1997). In particular, firms involved in radical innovation face both an unknown probability of success of their products, i.e. how likely it is to extract cash flows from these products, and an unknown extent of success of their products, i.e. what is the expected magnitude of the cash flows to be extracted from these products.

Which firms can handle these risks better? Firms that can spread risks over a larger asset or product base will face lower costs in raising money to develop or introduce a radical

innovation. Also, firms with more resources are in a better position to bear the costs, and support radical innovation (Cohen and Klepper 1996). Resource-rich firms may have a greater ability to absorb, interpret and commercialize critical information on a timely basis; this ability can, in turn, lower the risks that the firm faces (Lane and Lubatkin 1998). Moreover, at the introduction stage, marketing and organizational resources can also help the firm stabilize and grow the cash flows resulting from radical innovations.

The previous arguments point to a relative advantage of dominant firms, both in terms of who introduces and who gains more from radical innovations. But dominance and aggregate resources may tell only part of the story. Indeed, the literature in strategy and organizational theory emphasizes that the deployment of resources is as valuable as their magnitude (see Barney 1991; Makadok 2001). In addition to dominance, we highlight two aspects of resource deployment: *product support*, the extent to which the individual products are supported with marketing and technology resources upon introduction, i.e., firms' per-product levels of marketing and technology investments, and *product scope*, the extent of the product portfolio over which the radical innovation can subsequently be leveraged.

Who Introduces More Radical Innovations?

The literature presents conflicting conclusions about whether dominant or non-dominant firms are better at radical innovation (see Cohen 1995; Stringer 2000). Some researchers argue that dominant firms tend to be more bureaucratic (Tornatzky and Fleischer 1990) and may find it difficult to adapt and re-invent themselves when the technological environment changes. Alternatively, they may fail to evaluate the long-term market potential of new technology because the very basis of competition changes with it (Christensen 1997; Stringer 2000). Some organizational theorists also suggest that the research efforts of dominant firms are less productive than those of new entrants because dominant firms fail to update their set of

“information-processing assets” or to develop new ones (Arrow 1962; Nelson and Winter 1982). Furthermore, dominant firms may be less likely to introduce innovations as they have the potential to decrease the rents such firms extract from their current products (Chandy and 1998).

If bureaucracy, myopia and reluctance to change the status quo prevent dominant firms from introducing innovations in general, one would expect them to be even stronger deterrents of radical innovations. Recent empirical research, however, suggests the opposite. Using a retrospective coding of 64 radical innovations in two industries, Chandy and Tellis (2000) conclude that while small firms and new entrants introduced more radical innovations prior to the World War II, this trend reversed in recent times. What explains this change? The following paragraphs propose reasons why dominant firms may in fact introduce more radical innovations than other firms.

Radical innovations, as well as the technology necessary to generate them, have grown increasingly complex with time, and their undertaking requires sizeable resources (e.g., Mowery and Rosenberg 1998; Teitelman 1994). Dominant firms have greater resources: technological, financial, and market-related. These resources put dominant firms in a better position than non-dominant firms to handle the risks associated with radical innovation. Specifically, dominant firms enjoy economies of scale and scope in R&D (Scherer 1980; Teece 1980) and marketing (Comanor 1965). Economies of scale in R&D entail a more efficient use of research resources, which in turn allows firms to dedicate a larger fraction of resources to uncertain projects. Economies of scope, and the synergies they imply, may lead to a broader base of ideas that can be combined and materialized into new products. A greater knowledge base is also likely to be associated with higher absorptive capacity, the ability to recognize the value of new information, assimilate it, and apply it to commercial ends (Cohen and Levinthal 1990). This suggests that radical innovations are more likely to arise from well-funded, sophisticated research labs, where

numerous top scientists spend their days putting together the technologies of the future. Such labs are more likely to be found in dominant firms, which have the critical mass for research, and often have entire divisions dedicated to pioneering research.

Dominant firms also have better financial resources than non-dominant firms. They have greater access to funds to finance the risky pursuit of radical innovation and can spread these risks over a large volume of sales (Arrow 1962; Comanor 1965). Non-dominant firms, on the other hand, may not get second chances – their first failure may also be the last, as has often been shown to be the case with small firms (Dunne, Roberts, and Samuelson 1989).

Finally, economies of scale and scope in R&D suggest that dominant firms can diversify their research portfolios and introduce more of all types of breakthroughs: technological, market and radical innovations. While their technical capabilities help dominant firms create technological breakthroughs, the better understanding of the market and customers they obtained while building their market power offers them a competitive advantage in creating market breakthroughs.

For all these reasons—the necessity of handling the riskiness of radical innovations and their increased complexity—we expect the advantages of resources available to dominant firms to outweigh the pitfalls of their bureaucracy and inertia. Thus:

H1: Dominant firms introduce significantly more (1) radical innovations, (2) technological breakthroughs and (3) market breakthroughs than non-dominant firms.

Who Gains More from Radical Innovations?

“Innovate or Die? Sorry, that misses the point. There’s actually an innovation glut. The real shortage is profits.”(Fortune 2000, p. 225)

Recent research indicates that new product introductions can positively impact the market value and profitability of firms (e.g., Blundell, Griffith, and Van Reenen 1999; Geroski, Machin, and Van Reenen 1993), and that the more innovative these products are, the higher their financial

value. For instance, Chaney, Devinney, and Winer (1991) find that original new products have a higher financial value than updates of existing products, while Kleinschmidt and Cooper (1991) find that highly innovative products surpass moderately innovative products in terms of their success rate and return-on-investment.

But firms may not gain equally from innovation. Our thesis is that it is not just what is introduced that matters; it is also who introduces it. Investors value a new product based on how successful they expect the firm to be at commercializing it. Specifically, they evaluate the *likelihood* of success and the *level* of success that they expect the radical innovation to attain.

The product's level of success is based on the magnitude of the net cash flows that it can generate, relative to the investment made in the product. These cash flows depend in turn on the tangible and intangible resources that the firm can deploy to sustain and protect the innovation. In particular, dominant firms have higher marketing resources, such as advertising and promotional budgets, which can sustain the innovation and increase the adoption rate of the new product (Chandy and Tellis 2000). Through their involvement with previous generations of products, dominant firms are likely to have built a better knowledge base and a stronger set of market-based assets (Srivastava, Shervani, and Fahey 1998). Market-based assets such as brand equity can reduce the perceived risk that consumers associate with radical innovations (see Dowling and Staelin 1994). Dominant firms can also stimulate the adoption rate through superior access to distribution channels (Mitchell 1989).

Financial markets evaluate the product's likelihood of success based on how well the firm that introduces it can handle the uncertainty of the cash flows the product is expected to generate. Resources can both increase the magnitude and reduce the uncertainty of the cash flows that an innovation is expected to generate. Alternatively, this uncertainty is also related to the perceived riskiness of the firm. The literature in finance and industrial organization suggests

that dominant firms face less risk and that the market uses a smaller discount rate when evaluating their future prospects (e.g., Aldrich and Auster 1986). While lower perceived risk is mainly an indication of the stability of the firm, it is also an indication of its access to future resources. Even if current resources are not sufficient to sustain a radical innovation, dominant firms are better positioned than non-dominant firms to augment these resources through credit markets. Specifically, non-dominant firms face a disadvantage relative to dominant firms in the cost of external sources of funds. Evidence from Federal Credit Surveys suggests that, on average, small firms are more likely to face credit rationing (higher interest rates, smaller loans), which can impair growth or even lead to failure following the introduction of a new product (Scanlon 1984).

In sum, better current financial and organizational resources, as well as easier access to future resources, put dominant firms in a better position than non-dominant firms to undertake the risks of radical innovations, market breakthroughs and technological breakthroughs. Thus:

H2: Radical innovations, technological breakthroughs, and market breakthroughs introduced by dominant firms are valued more highly than those introduced by non-dominant firms.

In the following paragraphs, we explore what other factors, in addition to dominance (and aggregate resources), impact the value of radical innovations.

Aggregate Resources Alone Don't Tell the Full Story

Earlier in this section we argued that the financial value of a radical innovation will depend not only on the intrinsic advantages of the product over competing alternatives, but also on how well positioned the firm is to exploit these advantages (Kelm, Narayanan, and Pinches 1995). The highest economic returns will therefore go to firms that can extract the most rents from their products. We introduce the concepts of product support and product scope in support for the argument that it is not only resources in the aggregate that provide a competitive advantage to the firm, but also the firm's ability to *focus and leverage* its resources.

Product Support

We have previously argued that higher marketing and technology resources are one reason why the radical innovations introduced by dominant firms are valued more than those introduced by non-dominant firms. But some dominant firms may spread these resources over a larger number of products. This suggests that in addition to aggregate resources, it is also necessary to look at the *per-product* level of resources deployed by the firm. We define *product support* as the firm's marketing and technology investments per product. Product support addresses the firm's commitment to individual products, rather than its commitment to its entire product portfolio.

The role of marketing and technology investments in the success of new products has been well documented (e.g., Cooper and Kleinschmidt 1987; Yeoh and Roth 1999). These investments can build brand equity and create barriers of entry for competitors. Specifically, marketing builds awareness, which is essential for the success of a product that is completely new to consumers. Similarly, investors can view technology investments that are associated with the product (as reflected in patents and R&D spending) as evidence of higher quality, which is in turn associated with higher market value (Aaker and Jacobson 1994). Furthermore, a strong set of patents indicates that the firm's products are well protected from the early entry of competitors, which means that they will generate cash flows for a longer period of time (Bunch and Smiley 1992). However, investors evaluate innovations one at a time; therefore, in addition to evaluating a firm's overall set of patents, they will also value how well each innovation is protected by patents. This again highlights the importance of viewing resources on a per-product basis, besides doing so at an aggregate level.

In addition to their individual effects on financial value, marketing and technology investments may also play a joint role. For instance, Moorman and Slotegraaf (1999) predict that

both marketing and technology capabilities must be present for effective product development. Similarly, Dutta, Narasimhan, and Rajiv (1999, p. 547) find that “the most important determinant of a firm’s performance is the interaction of marketing and R&D capabilities”. Indeed, the value of marketing in supporting a new product would be diminished if the product has a shorter lifetime because it is not protected by a strong set of patents. Similarly, a strong set of patents cannot, by itself, increase the sales of a radically new product if the marketing resources necessary to create awareness and increase the speed of adoption are lacking.

Overall, the reasoning above suggests that investors will recognize that product support is a source of competitive advantage for firms that introduce radical innovations. Thus:

H3a: Radical innovations, technological breakthroughs, and market breakthroughs introduced by firms with high product support are valued more highly than those introduced by firms with low product support.

Product Scope

Theory on product sequencing (Helfat and Raubitschek 2000) suggests that the creation of new products depends on existing products, along with the underlying path-dependent knowledge and capabilities that the firm has. A radical innovation is a real option (e.g., Brown and Eisenhardt 1997), and an avenue of “preferential access to future opportunities” (Bowman and Hurry 1993, p.762). A firm with a broad product portfolio offers more opportunities for the radical innovation to be extended or leveraged – perhaps by developing other products based on the technology, or simply by cross-selling the innovation with other products - and as such can increase the future cash flows that are expected from the innovation.

We define *product scope* as the extent of a firm’s product portfolio within an industry. A greater product scope involves both a depth and a breadth of expertise dimension. A broad product scope is an indication of greater expertise in dealing with new products in various settings, and better ability to adapt the strategy for commercialization of each radical innovation.

Firms that extend their product portfolio in related areas, by building on their current knowledge base have been shown to obtain economies of scale, and synergies based on exchanges and transfers of skills and resources from one category to another (Aaker 1984). A firm with high product scope not only has more *opportunities* to leverage the new product in one of its areas of expertise (because of the breadth), but is also more likely to have the *ability* to leverage the product (because of the depth). This ability to exploit synergies can extend the commercial life of the radical innovation and can lead to more successful extensions, thus making the innovation more valuable.

A narrow product scope could also signal investors that the firm has a deeply embedded knowledge set and that its core competence, although well defined, is limited, and is associated with a certain rigidity in dealing with projects outside the scope of the core competence (Leonard-Barton 1992). Such a firm may thus lack the ability to identify all areas in which the radical innovation can be leveraged, or the expertise to leverage it. Furthermore, if the firm's product scope is narrow, and the new product is introduced within the firm's current scope, the risk of cannibalization increases. If the new product is introduced outside the firm's narrow scope, investors may fear that the firm has a limited experience in the new domain, which would be reflected in the stock market's evaluation of the product. We therefore hypothesize that:

H3b: Radical innovations, technological breakthroughs, and market breakthroughs introduced by firms with high product scope are valued more highly than those introduced by firms with low product scope.

Are All Breakthroughs the Same?

At first it may appear that market breakthroughs will be more highly valued by investors than technological breakthroughs, since their benefits are likely to be more apparent to consumers. But market breakthroughs are often not technologically advanced, or they involve technology that is no longer new, and as such they are easier to imitate than technological

breakthroughs. Thus, the economic rents that the firm may extract from market breakthroughs may be short-lived.

Although there is more uncertainty associated with technological breakthroughs, they are much more likely to be further leveraged than are market breakthroughs. Firms that initiate technological changes have been shown to grow more rapidly than other firms (Geroski, Machin, and Van Reenen 1993). Technological breakthroughs carry the promise of this growth, and investors will view them both as platforms for future product introductions and as signals that the firm is committed to, and successful at, the innovation process. They are “options” (Bowman and Hurry 1993; Sharp 1991) in the sense that they can offer new strategic choices for the firms, should the opportunity to leverage the technology in these products arise in the future.

Introducing market breakthroughs that are not technological breakthroughs may in turn signal a commitment for incremental innovation, and may position the firm as an entity that exploits existing knowledge, rather than one that strives to extend the frontier of knowledge (see Cohen and Levinthal 1990). We therefore hypothesize that:

H4: Technological breakthroughs are valued more highly than market breakthroughs. Radical innovations are valued the highest.

Overall, our hypotheses seek insights into the sources of radical innovations, as well as the financial gains that they generate. Drawing on marketing, strategy and industrial organization, these hypotheses highlight the role of risk and resources in determining the sources and consequences of radical innovation. In seeking to test the above hypotheses, one should bear in mind some of the limitations of existing research on radical innovation: small, convenience samples, potential self-report bias, and bias introduced by retrospective coding. The following section describes the data and methods used in this paper. The data and methods we use include a number of novel features that can help alleviate some of the methodological problems of past research.

Method

This section first presents an overview of the data and empirical context of the paper. It then describes how we translate each of our conceptual variables into empirical measures, and how we specify the models in the empirical analysis.

Data and Empirical Context

To test our hypotheses, we need:

- A comprehensive sample of radical innovations
- Objective measures of the radicalness of innovations
- A measure of the financial value of innovations, at the time the innovation is introduced
- A context with adequate variation in resources across firms, but which nevertheless allows for comparability in radical innovations across firms.

The pharmaceutical industry is a context that meets these requirements well. Because the Food and Drug Administration (FDA) has closely documented the pharmaceutical industry since 1939, the researcher has access to a uniquely rich trove of carefully compiled historical data. The industry is driven by innovations, yet there is enough variation in firms' resources to allow us to study their effect on the sources and consequences of radical innovations. Moreover, pharmaceuticals form a pillar of the national economy, and innovations in this industry can literally make the difference between life and death for individual consumers (Scherer 2000).

Restricting the empirical context to a specific industry allows for a degree of comparability between radical innovations that would be impossible to obtain in a cross-industry study. Comparing Viagra to, say, microwave ovens, is not an easy (or advisable) task. In the interest of internal validity, and given the lack of objective classifications in other industries, we concentrate on pharmaceuticals as our empirical context. In doing so, we follow in a long tradition of marketing researchers who have chosen this industry as their empirical context (e.g., Dekimpe and Hanssens 1999; Gatignon, Weitz, and Bansal 1990; Rangaswamy and Krishnamurthi 1991).

For the purposes of this research, perhaps the most attractive feature of the pharmaceutical industry is that it allows us to distinguish between incremental innovations, market breakthroughs, technological breakthroughs and radical innovations using an external, objective classification system. The FDA classifies new drugs along two dimensions at the time of approval: therapeutic potential and chemical composition. Based on their therapeutic potential, drugs are classified into two classes: *priority review drugs*, which represent a therapeutic advance over available therapy, and *standard review drugs*, which have therapeutic qualities similar to those of an already marketed drug. Based on their chemical composition, drugs are classified into *new molecular entities* and drugs that are either new formulations or have new indications of use. The new molecular entities (NME) are the most technologically advanced products, as they are based on an active ingredient that has never been marketed before. Table 2 presents the FDA definitions of these categories, as well as the operationalizations of the two types of breakthroughs and radical innovations.

The two dimensions of the FDA classification coincide precisely with the two dimensions in our classification of product innovation. Specifically, the FDA's therapeutic potential dimension corresponds to our customer benefits dimension, while the chemical composition dimension corresponds to our product technology dimension. Recall that a radical innovation is a product that involves a substantially new technology *and* provides substantially higher customer benefits relative to existing products. A market breakthrough provides substantially higher customer benefits, but its core technology is not substantially new. A technology breakthrough uses a substantially different technology than existing products, but does not provide substantially higher customer benefits. Based on these definitions, we classify product innovations as follows:

- Radical innovations: Priority review *and* new molecular entity (NME)
- Market Breakthroughs: Priority review, non-NME.
- Technology Breakthroughs: Standard review, NME.

Our sample is based on a census of innovations from 1991 to 2000, obtained from the NDA pipeline¹. The total number of products introduced in that period that were market breakthroughs, technological breakthroughs or radical innovations, was 380. We were able to retrieve accounting and financial information for 255 innovations. (226 of these had complete data on all measures of dominance, and 212 had complete measures on both dominance as well as stock market data.) 17 observations were eliminated from the analysis because of confounding effects of firm announcements unrelated to the approval of the drug. Specifically, we checked for equity offerings, earnings, dividend and M&A announcements made in the time window used in the NPV measure that could have distorted the abnormal returns.

The 255 breakthroughs in our sample come from 66 publicly traded firms. The total number of new products introduced by these firms in the 1991-2000 period was 3891. This number underlines the fact that breakthroughs are rare – they represent less than 7% of the total number of new introductions. The breakthroughs and radical innovations that are excluded from our sample come from divisions of large conglomerates, from private firms, from firms that were no longer in business in 2000 (and for which financial data is unavailable), or from joint ventures (Table 3). The figures presented in Table 3 indicate that our focus on public companies does not cause us to disproportionately include innovations by dominant firms in our sample. The innovations that we dropped from our sample that were introduced by non-dominant firms are roughly equal in number to the dropped innovations introduced by dominant firms.

The 66 firms in our sample are headquartered in seven countries: US, UK, France, Belgium, Switzerland, Germany, and Japan. Four of the firms in the dataset were acquired before the year 2000. For these firms we included accounting data until the year of their acquisition;

data in the remaining years, we treated as missing. Testing the hypotheses required compiling data from 14 different databases. Table 4 lists the variables and the sources of data used in the study.

Measures and Models

The sample is a cross-sectional time series data set consisting of 255 breakthroughs introduced by 66 firms over a 10-year period. We therefore need to analyze an unbalanced panel of data. We also need to choose appropriate econometric models to accommodate the two dependent variables of interest (the number and the financial value of radical innovations) as well as account for any unobserved heterogeneity due to firm specific effects.

As noted earlier, the literature suggests that dominance is a multidimensional construct that involves three variables: market share, assets and profits (e.g., Borenstein 1990, 1991; Pleatsikas and Teece 2001). Principal factor analysis generates a common factor that captures information from all three components of dominance. We therefore operationalize *dominance* as the factor score associated with this factor. This operationalization incorporates not only the multi-faceted nature of dominance, but also its relationship to one of our key theoretical constructs: firm resources. A dominant firm is therefore more than a large firm; it is a profitable firm with resources.

Because all our data come from one industry, we use firm sales as a proxy for market share. Profits are estimated as the product of assets and return on assets. To check for robustness, we also conduct additional analyses using employees as a measure of dominance (e.g., Yeoh and Roth 1999).

Measures and Model for the Test of Who Introduces More (H1):

To assess who introduces more radical innovations, the dependent variable is the *count* of radical innovations introduced in each year by various firms (e.g., Baltagi 2001; Blundell,

Griffith, and Van Reenen 1999; Hausman, Hall, and Griliches 1984). This variable has two unique properties: 1) it is non-negative (e.g., a firm cannot have -5 innovations), and 2) it involves integers (e.g., a firm cannot have 2.35 innovations). OLS is inappropriate for count data. Moreover, the data extend over multiple years for the same firms; i.e., they form a time-series cross-sectional *panel*. We account for these properties by using, in the tradition of Blundell, Griffith and Van Reenen (1999) and Hausman, Hall, and Griliches (1984) among others, a Poisson model to test H1. The basic Poisson probability specification is:

$$P(n_{it}) = \frac{\exp(-I_{it}) I_{it}^{n_{it}}}{n_{it}!} \quad (1)$$

where n_{it} = the innovation count for firm i in year t .

We model the parameter \tilde{I}_{it} as a function of dominance and a set of control variables. In addition to controlling for time and the country in which the firm is based, we include two measures of overall firm innovativeness as control variables: number of incremental innovations introduced and number of patents applied for in each year. While we do not formally hypothesize a relationship between radical innovativeness and the firm's incremental innovation output, this model allows us to also explore whether radical innovations are "accidents" or part of a more substantial innovation output at the firm level. We include a dummy for country (US/non-US) in the model to account for any possible effects in valuation that may exist between US and non-US firms.

The panel nature of the data also allows us to control for firm specific unobserved heterogeneity. We use a random effects model, and specify the Poisson parameter \tilde{I}_{it} as follows:

$$\begin{aligned} \tilde{I}_{it} &= \tilde{a}_i = \exp(X_{it} \beta + \mu_0 + \mu_i) \\ &= \exp(\beta_1 \text{Dominance}_{it} + \beta_2 \text{No.Prod}_{it} + \beta_3 \text{No.Patents}_{it} + \beta_4 \text{Country}_i + v \text{Year} + \mu_0 + \mu_i) \end{aligned} \quad (2)$$

where:

$\tilde{\alpha}_i$ is a random firm specific effect;

the following three variables are control variables:

No.Prod_{it} are the number of incremental products introduced in the same year with the radical innovation;

No.Patents_{it} are the number of patents applied for in the year the radical innovation was introduced;

Country_i is a dummy that takes the value 1 if the drug is introduced by a firm headquartered in the US and 0 otherwise;

Year is a matrix of dummies for year of introduction;

μ_i is the unobserved firm specific effect; and

μ_0 is the overall intercept.

The Poisson probability specification now becomes:

$$P(n_{it} / X_{it}, \mu_i) = \frac{\exp(-\lambda_{it} \exp \mu_i) (\lambda_{it} \exp \mu_i)^{n_{it}}}{n_{it}!} \quad (3)$$

And the joint density is:

$$P(n_{i1}, \dots, n_{in_i} / X_i, \mathbf{m}_i) = \left(\prod_{t=1}^{n_i} \frac{I_{it}^{n_{it}}}{n_{it}!} \right) \exp \left\{ -\exp(\mathbf{m}_i) \sum_{t=1}^{n_i} I_{it} \right\} \exp \left(\mathbf{m}_i \sum_{t=1}^{n_i} n_{it} \right) \quad (4)$$

We test for the equality of the mean and variance in the Poisson distribution and the appropriateness of a negative binomial specification as part of a robustness check for the counts model. We also check the results from a fixed effects (rather than random effects) specification of unobserved heterogeneity. We report the results of these checks in a later section below.

Measures and Model for the Test of Who Gains More (H2-H4):

Measuring Innovation Valuation: Srivastava, Shervani, and Fahey (1998) have argued that the key to bridging research in marketing and finance lies in examining the impact of various marketing actions and market-based assets on a firm's cash flows, which ultimately define

shareholder value. In line with this argument, we assess the financial value of radical innovations using the concept of *Net Present Value* (NPV) which captures the expected value of all future discounted cash flows generated by the innovation (Fisher 1965; Ross, Westerfield, and Jaffe 1999). A discussion of how NPV is measured, as well as its theoretical and managerial implications, is given in Appendix 1.

Measuring Product Support: We have defined product support as the level of a firm's marketing and technology investments per product. Product support has two components: *marketing support and technology support*. We assess marketing support based on investments in the firm's salesforce. (Later in the paper, we report results from a measure of product support that also includes direct-to-consumer advertising). Since salesforce expenditures are considered to be the most important promotional expenditures in the pharmaceutical industry (e.g., Yeoh and Roth 1999), we have obtained three measures of firm investments in their salesforce: the size of the salesforce, the number of sales calls placed by the salespeople, and the amount of dollars that the firm has spent on its salesforce. This data were purchased from Verispan, a marketing research firm that tracks the performance and investments made by pharmaceutical firms. We compute the relative size of these marketing investments to the number of new products introduced per year. Specifically, we operationalize marketing support by using the factor scores from a principal component analysis on the relative measures of salesforce. Similarly, we assess technology support based on the firm's R&D expenditures as well as the patent support that the firm's products enjoy. We use citation-weighted patents in light of recent research that shows that citation-weighted patents are a better measure of a firm's ability to appropriate returns from its innovations than unweighted patents (Hall, Jaffe and Trajtenberg 2000). We compute the relative size of the R&D investments and citation-weighted patent stocks to the number of new products introduced per year. We then operationalize technology support by using the factor

scores from a principal component analysis on the relative R&D and patents measures. We measure product support as the sum of the (standardized) marketing and technology support variables.

Measuring Product Scope: We define *product scope* as the extent of a firm's product portfolio within an industry. By definition, product scope is more than a mere measure of the diversification of a firm's product portfolio. It is a measure of the breadth of its expertise as well as the depth of the multi-faceted knowledge that arises from introducing many innovations across multiple product categories. We therefore have to modify existing measures of diversification to account not only for the breadth of the product portfolio but also its overall depth.

One of the most commonly used measures of diversification is entropy (Varadarajan 1986):

$$E = \sum_{j=1}^n p_j \ln(1/p_j) \quad (5)$$

where :

$p_j = P_j/P$ is the fraction of the firm's products in the j -th product category relative to its overall product portfolio;

P_j is the number of products in a specific therapeutic category (as defined by the FDA classification of these categories) that the firm has at time t ;

P is the firm's overall number of products at time t .

The entropy measure does not differentiate between firms that have the same breadth of product portfolio but different depths. A firm with 5 products, one in each of five different product categories, will have the same entropy as a firm with 500 products, 100 in each different product category. Our conceptual definition of scope, as we note above, also takes into account the depth of the product portfolio, since it rests on theoretical arguments related to the firm's

knowledge base. We therefore multiply the entropy measure by the overall number of products in the product portfolio to obtain a measure of product scope:

$$ProductScope = E \cdot P = \left[\sum_{j=1}^n \frac{P_j}{P} \ln \left(\frac{P}{P_j} \right) \right] P = \sum_{j=1}^n P_j \ln \left(\frac{P}{P_j} \right) \quad (6)$$

Quantifying product scope requires the collection of data on *all* the innovations that are currently in the portfolio of the 66 firms in our sample. The data comes from the National Drug Code Directory database. The National Drug Code Directory (NDC) is an FDA-maintained database that the FDA describes as “a universal product identifier for human drugs”. The NDC database not only contains all the drugs available in the United States that have been approved by the FDA, but it also classifies these drugs into 21 major therapeutic categories which are in turn divided into subcategories. We use these major therapeutic categories to define each firm’s product categories and to construct product scope in Equation 9. Our data covers drugs introduced since 1970. We use a rolling window of 17 years (to correspond to the duration of the patent life) to count a product in a firm’s product portfolio. We also conduct additional analyses on rolling windows of 14 and 21 years to test the robustness of the results.

Model for H2-H4:

To test H2 – H4 we estimate the following model (e.g., Baltagi 2001; Dutta Narasimhan and Rajiv 1999; Geroski, Machin, and Van Reenen 1993):

$$\begin{aligned} NPV_{it} = & \beta_0 + \beta_1 Dominance_{it} + \beta_2 ProdSupport_{it} + \beta_3 ProdScope_{it} \\ & + \beta_4 RI_{it} + \beta_5 MB_{it} + \beta_6 Licensed_{it} + \beta_7 WACC_{it} + \beta_8 Country_i \\ & + \beta_9 NRI_{it} + \gamma Year + \lambda Category + ?_i + ?_{it} \end{aligned} \quad (7)$$

where:

RI_{it} , MB_{it} = dummy variables with value 1 if the product is a radical innovation (respectively a market breakthrough) and 0 otherwise; the effects of RI_{it} and MB_{it} are therefore interpreted relative to the third type of innovation, TB_{it} ;

$Licensed_{it}$ = a dummy variable with value 1 if the product was invented by the firm that introduced it and 0 otherwise;

$WACC_{it}$ = cost of capital for firm i in year t (see appendix 2 for a description of this variable);

NRI_{it} = is the number of breakthrough innovations introduced by firm i in year t ;

Year = matrix of dummies for the year in which the innovation was introduced ;

Category = matrix of dummies for the therapeutic class to which the drug belongs;

ϵ_i = the unobserved firm specific effect.

Results

Who Introduces More Radical Innovations?

A major concern in assessing the sources of radical innovation is in distinguishing between who invented versus who introduced the innovation. It is conceivable that entrepreneurs may develop a radically new product, but may not have the means to commercialize it, and may wind up selling it to a larger organization. Since dominance is a central variable in our study, it is especially important to account for this possibility. FDA data indicates only to whom the approval to market the drug was granted and so we also have to determine the original source of the innovation, its inventor. A comprehensive search that included the Pink Sheets (detailed newsletters about pharmaceutical and biotechnology products published by FDC), the Pharmaprojects database of pharmaceutical projects, and trade press articles published while the drugs were in development, allows us to determine that the original inventors introduced 193 or about 75% of the 255 breakthroughs studied, while 62 breakthroughs were licensed or bought from other firms. Only about 25% of the radical innovations introduced by dominant firms were licensed or acquired before FDA approval, while the rest were invented in-house by these firms. Also, because the Bayh-Dole Act sets up considerable incentives within the pharmaceutical industry for commercializing university research, we also use the Pharmaprojects database to check how many of the drugs in our database were invented in universities. We find that only 4

of the 255 drugs in our dataset were invented in universities. We further address the issue of invention versus product acquisition in analyses we present later in this section. Hypothesis H1 suggests that dominant firms introduce more radical innovations and more breakthroughs than non-dominant firms. Dominance is significant as a continuous variable in the Poisson model that predicts the count of innovations ($e^{\beta} = 1.58$; $p < 0.001$; see Table 5 for the results). For ease of exposition, the coefficients for the time dummies are not included in this table. A significant covariate of the count of radical innovations is the number of incremental new products introduced in the same year as the radical innovation ($e^{\beta} = 1.02$; $p < 0.001$). The number of patent applications submitted by the firm, a common measure of innovativeness previously used in the literature, was not significant ($p = 0.44$). Even after accounting for whether the innovation was invented in-house or acquired, dominant firms still introduce more radical innovations. There is no significant difference between the proportion of licensed innovations introduced by dominant versus non-dominant firms (likelihood ratio $\chi^2 = 0.51$, $p = 0.48$). We obtain similar results, with the same level of significance, if we use: 1) firm size (operationalized in terms of number of employees) instead of the measure of dominance reported here, and 2) a fixed effects specification of firm-specific unobserved heterogeneity instead of the random effects specification reported here. We also used a negative binomial model of counts, instead of a Poisson model. The overdispersion parameter is not significantly different from zero; thus the negative binomial distribution is equivalent to the Poisson distribution.

To get a better feel for the difference between dominant and non-dominant firms, we also present a bivariate categorical analysis of the innovation counts. For exposition purposes, we use a median split on dominance among our sample of 66 radical innovators². Figure 1 suggests that dominant firms introduce more than twice as many radical innovations and breakthroughs as non-dominant firms. Although we draw our data from a single industry, this result is in line with

the findings of Chandy and Tellis (2000) who use data on radical innovations in different industries. The convergence in findings offers some confirmation of the external validity of our results.

Our data also indicate that dominant firms have the advantage for all three types of products studied: they introduce more radical innovations, market breakthroughs and technological breakthroughs (Figure 2). The highest difference arises in the case of the technological breakthroughs. This suggests the possibility of economies of scale in R&D for dominant firms.

Table 6 presents a ranking of the top 15 firms with the largest number of breakthrough innovations. It is interesting to note that the top 15 most innovative firms introduced 161 breakthrough innovations - more than half the number of all breakthrough innovations introduced in the entire 1991-2000 period. Results in the table also indicate that firms who introduce more radical innovations also tend to introduce more incremental innovations. Thus, contrary to popular belief (e.g., Utterback 1996), radical innovation is not necessarily a substitute for incremental innovation – the two appear to go hand in hand among the most innovative firms.

Who Gains More from Radical Innovations? How do Product Support and Product Scope Impact the Gains from Radical Innovation?

Hypothesis H2 argues that dominant firms gain more from radical innovation. H2 is supported: results suggest that while a really new product introduced by a dominant firm is valued at about \$456 million, it is only valued at about \$37 million if it comes from a non-dominant firm (Figure 3). This difference is significantly different from zero ($p < 0.01$). Again, if firm size (number of employees) is used instead of the composite measure of dominance, the differences between dominant and non-dominant firms are even more pronounced. Dominance is also significant as a continuous variable in all three random-effects models we test (see Table 8). A ranking of the highest NPV drugs is presented in Table 7.

To estimate the effect of product support we first run separate principal component analyses on the three salesforce measures to extract a measure of marketing support, and on R&D expenditures and citation-weighted patents to extract a measure of technology support. We then compute product support as the sum of marketing and technology support. The standardized coefficients for product support ($\beta=0.38$; $p<0.001$) and product scope ($\beta=0.26$; $p<0.05$) are significant and adding these variables to the model more than doubles the R^2 . Therefore H3a and H3b are supported too: having higher support and scope significantly increases the financial value of a radical innovation. (Table 8 presents the results for the model with and without product support and product scope.)

Further, product support and scope can explain differences in the NPV of radical innovations even among dominant firms (firms with higher than the median value on the dominance factor score). Figures 5 and 6 show the average NPV for dominant firms with high versus low product support, and product scope respectively. These differences are statistically significant for both support ($p<0.05$) and scope ($p<0.01$). We report the results for product scope using a 17-year rolling window, but significance is also maintained if we use a 14- or a 21-year window. We control for the therapeutic class to which the drug belongs; only the coefficient for the therapeutic class “diuretics” is significant. None of the year dummies is significant. To conserve degrees of freedom, we do not include the non-significant therapeutic class and year dummies in the final model. We also check whether the market reaction to the drugs introduced by biotech firms is different from the reaction to drugs introduced by all other firms. We find no significant differences between the two types of firms. To further explore the relationship between dominance, support and scope we present results from four additional analyses. First, we examine the effects of product support with its components, marketing and technology support, included separately in the model. The results in Table 8 (Model 3) indicate that both

components of product support—marketing support ($\beta=0.34$; $p<0.001$) and technology support ($\beta=0.49$; $p<0.05$)—have a significant positive effect on NPV. Further, including the two components maintains the significance of the other relevant independent variables³.

Second, we expand the operationalization of product support by including advertising as an additional component of marketing support. In recent years, direct-to-consumer advertising has been viewed as an increasingly important marketing expenditure by pharmaceutical firms. We were able to collect advertising data, however, for only 16 firms in our sample, corresponding to 85 innovations. We find that advertising expenditures are highly correlated with the other marketing variables: the correlation between advertising and dollars spent on sales calls is 0.80 ($p<0.001$) and that between advertising and number of calls is 0.83 ($p<0.001$). The sign of the coefficients, as well as their significance levels, are maintained when advertising is added to the marketing support variable in our random effects model (see Table 9). We report the results of this analysis separately, since advertising data is only available for a limited sub-sample of firms and since its inclusion does not substantively modify the results.

Third, we also checked for any significant interactions between dominance and product support, using dummies based on median splits. The results show that the highest value is created for high dominance, high product support firms. The NPV for high dominance, high support is significantly higher ($p<0.05$) than the NPV for high dominance, low product support. Also, the NPV for low dominance, high support is not significantly different from high dominance, low support ($p=0.84$). Thus, investment in product support may provide non-dominant firms with a means to equalize their NPV position relative to low-support dominant firms.

Finally, we checked to see if non-dominant firms provide more monetary incentives to their salespeople. In theory, such firms could seek to compensate for their smaller sales forces by

spending more per sales person, and per sales call. Empirically, we find that the average detailing expenses per salesperson over the 1991-2000 period were \$116,000 and \$79,000 for dominant and non-dominant firms respectively. Also, the dominant firms in our sample spent an average of \$132 on a sales call while non-dominant firms spent an average of \$129. Overall, these richer measures provide additional evidence on the resource advantage of dominant firms.

Are Different Breakthroughs Valued Differently?

H4 maintains that technological breakthroughs will be valued more highly than market breakthroughs, and radical innovations will be valued the highest of all. H4 is partially supported: radical innovations are valued significantly higher than either technological or market breakthroughs (see Table 8). We do not, however, find any significant differences between the financial valuation of technological and market breakthroughs. While technological breakthroughs have a higher mean value, their variance is also higher, highlighting their riskiness. Figure 4 presents the net present value of the three types of innovations.

Short-term versus long-term horizon

Using recent methodology from the finance literature (Barber and Lyon 1997; Mitchell and Stafford 2000) we also computed one- and two-year buy and hold long-term abnormal returns for the firms in our sample. Given the newness of radical innovations, we were concerned about the possibility that their effect on the market value of a firm may not be entirely captured by the short-term abnormal returns around the announcement. The long-term results reveal no overall abnormal returns above and beyond the short-term ones (p-values for the tests of zero one-year and two-year buy-and-hold abnormal returns were higher than 0.10). Moreover, the results show no significant differences between the dominant and non-dominant firms in the long-term. The stock market appears to incorporate most information about the expected

financial value that a radical innovation can add to the firm within two days from the announcement date. Additional details of this analysis are available from the authors.

Generalizations and Limitations

The pharmaceutical industry provides a clean, data-rich, and economically and socially important context for this study. But it is always perilous to speculate about the applicability of results from one industry to others. The remarkable advantage that we find dominant firms enjoy in the radical innovation process may raise questions about the generalizability of our results. For example, it could be that the pharmaceutical industry is highly concentrated and small players cannot break the barriers of entry imposed by their larger counterparts. If this were true, then making generalizations would be especially imprudent. Some commonly studied industries in the context of innovation are household appliances, electronic computer manufacturing, fiber optic cable manufacturing, and semiconductor manufacturing. As data from the *US Economic Census* (1997a) shows, the pharmaceutical industry is in fact *less* concentrated than most of these industries.

Another cause for concern could be that non-dominant firms are disadvantaged because of the long process involved in obtaining FDA approval for innovations; non-dominant firms may therefore lack the incentive to innovate. However, innovations in this industry are also well protected by patents, thus sheltering innovations by small firms, and encouraging such firms to dedicate resources to innovation. The Waxman-Hatch Act of 1984 includes provisions that can extend the patent life for a drug that was delayed in the approval process by up to five years, increasing the chances that firms may collect economic rents from their drugs above and beyond their initial R&D investments (Scherer 2000). Indeed, a number of authors have noted that firms in the pharmaceutical industry enjoy a relatively high level of appropriability of the returns from innovations (Gambardella 1995). They also have greater access to venture capital than firms in

many other industries (Fugazy 2002). All of these factors could help protect the investments of non-dominant firms, and may help explain why firms with less than 100 employees account for 73.83% of all pharmaceutical firms (*US Economic Census 1997b*). The long approval process does not appear to uniquely hinder the participation of non-dominant firms—at least not much more than in other technology-intensive industries.

Implications

Theoretical and empirical arguments have long indicated that dominant firms are proficient at making incremental changes to existing products, but inept at commercializing breakthrough ideas. Stringer (2000, p. 71) notes that “[they] seem to be “genetically” incapable of commercializing radical innovation and they cannot bring themselves to learn by doing”. Henderson (1993, p. 268) suggests that such firms are “significantly less productive than entrants in their attempt to introduce innovations that were radical.” Our findings point to the contrary: dominant firms introduce significantly more radical innovations than non-dominant firms. Moreover, non-dominant firms suffer from double jeopardy in the radical innovations game: not only do they introduce less radical innovations than the dominant firms, but their innovations are also valued less by the stock market.

Perhaps the main theoretical implication of this study is that the value of radical innovations—namely products that provide substantially higher benefits for consumers and include substantially new technology—cannot transcend the characteristics and capabilities of the firms that introduce them. A radical innovation is only as good as the firm that commercializes it.

Contradicting the oft-held belief that new, discontinuous technologies signal the swan song of dominant firms because these firms don’t recognize the markets for such technologies, our results suggest that radically new technology can actually *reinforce* the market position of

dominant firms by generating larger cash flows than the technology can for their non-dominant counterparts. Our results also offer a rationale for the consolidation trend in the pharmaceutical industry, which has increased at a brisk pace in the last decade: firms are possibly seeking the economies of scope that would increase their productivity, innovativeness, and profitability.

Do the results of our paper mean that small, non-dominant firms are doomed in their quest for radical innovations? Not necessarily. But in addition to firm level resources, the stock market also recognizes the extent to which the firms deploy these resources at the product level. Our results indicate that high product support increases the value of breakthrough innovations, offering a means for non-dominant firms to gain from innovations by focusing their resources on key products. A medium-sized firm that deploys high levels of technology and marketing support toward its key products could potentially have radical innovations that are as valuable (or more) as the ones from a dominant firm that fails to support its products adequately.

Our findings also offer the managers of non-dominant firms an indication of how much their breakthrough innovations are worth, both to them and to a dominant firm—or a firm with higher marketing expertise—that would be interested in marketing their products. The large differences in valuation uncovered in this analysis leave considerable room for licensing activities that would benefit both the small inventors as well as the large firms that are better positioned to commercialize these inventions.

In a marketplace with intense competitive forces, radical innovations could arguably have been the last type of product for which the old belief “make a good product and customers will beat a path to it” was still applicable. This paper suggests that dominant firms are able to build “highways” to their radical innovations, and gain more from their products. An unequal path leads even to the best products - a path that depends upon the resources of the firm that introduces the innovation.

Table 1

Types of Product Innovations

		<i>Customer Need Fulfillment</i>	
		Low	High
<i>Newness of Technology</i>	Low	Incremental innovation	<i>Market breakthrough</i>
	High	<i>Technological breakthrough</i>	<i>Radical innovation</i>

Source: Chandy and Tellis (1998)

Table 2

FDA Definitions and Operationalization of Innovations

Food and Drug Administration (FDA) Definitions

Chemical Composition	<i>New molecular entity (NME)</i>	An active ingredient that has never been marketed in this country.
	<i>Update</i>	A drug that is either a new formulation, new dosage of existing components or is a commercialized drug that has a new usage.
Therapeutical potential	<i>Priority review drug</i>	A drug that appears to represent an advance over available therapy.
	<i>Standard review drug</i>	A drug that appears to have therapeutical qualities similar to those of an already marketed drug.

Operationalization of Innovations

		<i>Therapeutical potential</i>	
		Standard review	Priority review
<i>Chemical Composition</i>	Update	Incremental innovation	<i>Market breakthrough</i>
	NME	<i>Technological breakthrough</i>	<i>Radical innovation</i>

Table 3
Description of the Census of Radical Innovations
in the Pharmaceutical Industry during 1991-2000

<i>Nature of breakthroughs</i>	<i>Details</i>	<i>Detailed count</i>	<i>Count</i>
<i>Used in the sample (introduced by public firms)</i>		226	226
Introduced by public firms in the sample, but for which data on one of the three components of dominance, or stock market data, was missing in the year the product was introduced		29	29
Introduced by divisions of dominant firms	division of 3M	1	22
	division of BASF	3	
	division of Ciba Geigy (Ciba Vision)	3	
	division of DuPont	3	
	division of Kodak (Sterling)	1	
	division of Merck KGaA	1	
	division of Nestle	7	
	division of Procter and Gamble	1	
	division of Sigma-Tau Pharma – IT	1	
	division of Snow brand milk products - JP	1	
Introduced by firms that were acquired before 2000 and for which financial data is unavailable	Upjohn -acquired in 1995	18	31
	American Cyanamid - acquired in 1994	1	
	Ciba - acquired in 1996	3	
	Syntex - acquired in 1994	1	
	Wellcome - acquired in 1995	8	
Introduced by private firms		32	32
Introduced by public firms for which financial data is unavailable		37	37
Introduced by joint ventures of public firms	joint venture of Astra and Merck	1	3
	joint venture of Abbott and Takeda	1	
	joint venture of L'Oreal and Nestle	1	
<i>Total</i>		<i>380</i>	<i>380</i>

Table 4
Variables and Data Sources Used in the Study

<i>Conceptual variable</i>	<i>Measured variable</i>	<i>Data source</i>
Dominance	$f(\text{Sales, Assets, Profits})$	<ul style="list-style-type: none"> • COMPUSTAT, DataStream, Standard and Poor's
Type of breakthroughs	Market breakthrough: FDA priority review Technological breakthrough: FDA NME classification Radical innovations: NMEs that are also priority review drugs	<ul style="list-style-type: none"> • NDA Pipeline • FDC Pink Sheets
Value of radical innovations	Net present value	<ul style="list-style-type: none"> • CRSP • DataStream
Marketing support (product support)	Sales force/No. of new products Number of sales calls/ No. of new products Detailing dollars/ No. of new products Advertising Expenditures	<ul style="list-style-type: none"> • Verispan (Scott Levin Inc.) • NDA Pipeline • Schonfeld & Associates
Technology support (product support)	Citation-weighted patents/No. of new products R&D expenditures/ No. of new products	<ul style="list-style-type: none"> • US Patent and Trademark Office Database • COMPUSTAT
Product scope	Entropy x (Number of new products)	<ul style="list-style-type: none"> • National Drug Code Directory • FOI Database of Drugs
Original source of innovation	Dummy for inventor	<ul style="list-style-type: none"> • Pharmaprojects • FDC Pink Sheets • Lexis-Nexis
Riskiness of projects undertaken by the firm	Cost of capital	<ul style="list-style-type: none"> • LB Fixed Income Research Program • DataStream etc.

Table 5
Innovation Counts: Results from the Random-Effects Poisson Model

<i>Dependent variable: Number of breakthrough innovations</i>	
	<i>Incidence Rate Ratio (e^b)</i>
Dominance	1.58***
Number of new products introduced in the same year	1.02***
Number of patents applied for in the same year	1.00
Country	0.95
<i>Log likelihood</i>	-383.12
<i>Wald χ^2</i>	116.72***

*** p<.01

Table 6
Firm-Level Innovation Ranking and Innovation Counts: 1991-2000

<i>Company</i>	<i>All Breakthroughs</i>	<i>Radical Innovations</i>	<i>Total Innovations</i>
GlaxoSmithKline	19	8	382
Roche	15	7	147
Bristol-Myers Squibb	15	4	320
SmithKline (before merger with Glaxo)	12	4	177
Abbot Laboratories	11	2	284
Merck	11	7	489
Johnson&Johnson	10	2	136
Aventis Pharma	9	4	83
Hoechst	9	3	79
Novartis	9	0	163
Wyeth	9	2	144
Pfizer	9	1	118
Parke -Davis	9	4	93
AstraZeneca PLC	8	0	117
Eli Lilly	6	2	231

Table 7
Ranking of Highest Net Present Value Drugs: 1991-2000

<i>Drug Name</i>	<i>Drug Class</i>	<i>Company</i>	<i>Approval Date</i>	<i>Innovation Type</i>	<i>Licensed</i>	<i>NPV (in \$ mil.)</i>
<i>Singulair</i>	Respiratory; Pulmonary Asthma/Anti-Asthmatic	Merck	20-Feb-98	Tech breakthrough	No	6981.7
<i>Tikosyn</i> <i>Dofetilide</i>	Cardiovascular; Arrhythmia/Anti- Arrhythmic	Pfizer	10-Jan-99	Tech breakthrough	No	6313.5
<i>Viagra</i>	Gynecological; Genito- Urinary Impotence	Pfizer	27-Mar-98	Radical Innovation	No	6189.9
<i>Rapamune</i>	Immunology/Autoimmune Disease	Wyeth-Ayerst	15-Sep-99	Radical Innovation	No	5745.0
<i>Mylotarg</i>	Cancer; Blood Cancer; Leukemia	Wyeth_Ayerst	17-May-00	Radical Innovation	No	5552.9
<i>Glucovance</i>	Metabolic Disorders; Diabetes; Diabetic Complications	Bristol-Myers Squibb	31-Jul-00	Tech breakthrough	Yes	5428.8
<i>Rebetron</i>	Infectious Diseases & Viral Diseases; Antiviral Hepatitis	Schering-Plough	3-Jun-98	Market Breakthrough	Yes	4910.0
<i>Aggrastat</i>	Cardiovascular	Merck	14-May-98	Radical Innovation	No	4807.4
<i>Relenza</i>	Infectious Diseases & Viral Diseases; Antiviral Influenza	GlaxoSmithKline	27-Jul-99	Radical Innovation	Yes	4112.7
<i>Temodar</i>	Cancer, Brain Cancer	Schering-Plough	11-Aug-99	Radical Innovation	Yes	3281.4

Table 8

Results: Financial Value of Innovations

	<i>Model 1</i> <i>(n=195)^a</i>	<i>Model 2</i> <i>(n=117)^a</i>	<i>Model 3</i> <i>(n=117)^a</i>
Dominance	0.16**	0.51**	0.50**
Radical innovation	0.17**	0.31***	0.30***
Market breakthrough	0.06	0.11	0.11
Product Support	--	0.38***	--
Marketing Support	--	--	0.34***
Technology Support	--	--	0.49**
Product Scope	--	0.26**	0.23*
Number of breakthroughs	0.04	0.15	0.15
Cost of capital	0.10	0.35***	0.33**
Diuretics	0.17**	0.54	0.50
Country	-0.09	0.06	0.04
Licensed	-0.06	-0.13	-0.14
<i>Wald χ^2 Statistic</i>	23.55	48.37	48.55
<i>(p-value)</i>	0.0027	<0.0001	<0.0001
R ² within	0.09	0.29	0.28
R ² between	0.14	0.24	0.24
R² overall	0.11	0.31	0.31

* p<.10

** p<.05

*** p<.01

^a Standardized coefficients

Table 9

Financial Value of Innovations: Results Incorporating Advertising

	<i>Model 1 (n=85)^a</i>	<i>Model 2 (n=85)^a</i>
Dominance	0.63**	0.60*
Radical innovation	0.38***	0.38**
Market breakthrough	0.00	-0.02
Product Support	0.48***	--
Marketing Support	--	0.49***
Technology Support	--	0.47*
Product Scope	0.37**	0.39**
Number of breakthroughs	0.12	0.14
Cost of capital	0.51***	0.56***
Diuretics	0.25	0.15
Country	0.45**	0.44*
Licensed	-0.10	-0.09
<i>Wald χ^2 Statistic</i>	<i>51.17</i>	<i>49.20</i>
<i>(p-value)</i>	<i><0.0001</i>	<i><0.0001</i>
R ² within	0.38	0.38
R ² between	0.44	0.43
R² overall	0.40	0.40

* p<.10

** p<.05

*** p<.01

^a Standardized coefficients

Table 10
Industry Concentrations

<i>Industry</i>	<i>Prior Research</i>	<i>Value of shipments accounted by the largest 20 companies (%)</i>	<i>Herfindahl- Herschmann index for the 50 largest companies</i>
<i>Pharmaceuticals</i>	Dekimpe and Hanssens (1999) Gatignon, Weitz, and Bansal (1990) Rangaswamy and Krishnamurthi (1991)	69.7	441.5
<i>Household appliances</i>	Sultan, Farley, and Lehmann (1990) Chandy and Tellis (2000)	82.7	839.8
<i>Electronic computer manufacturing</i>	Chandy and Tellis (1998) Eisenhardt and Tabrizi (1995)	90.0	658.2
<i>Semiconductors</i>	Dutta, Narasimhan, and Rajiv (1999)	62.1	688.7

Figure 1

Number of Breakthroughs Introduced by Dominant and Non-Dominant Firms

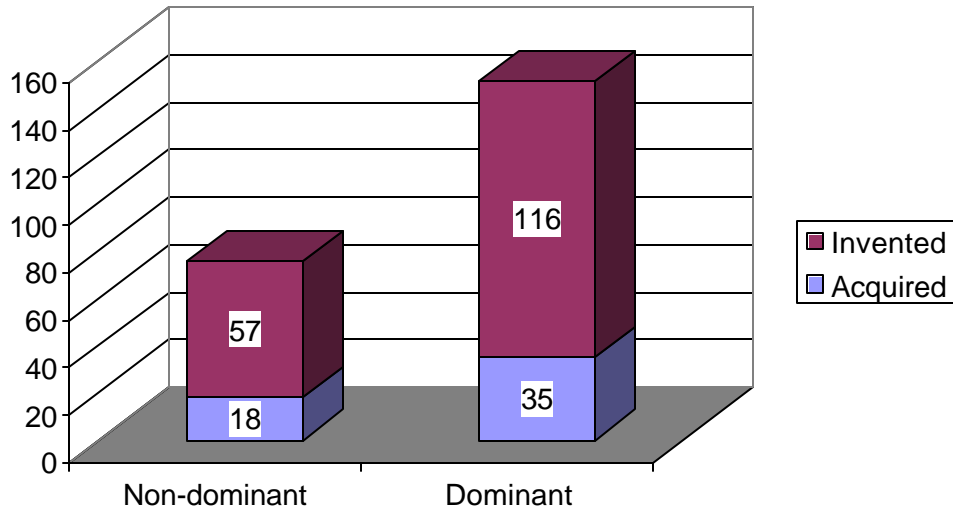


Figure 2

Types of Breakthroughs Introduced by Dominant and Non-Dominant Firms

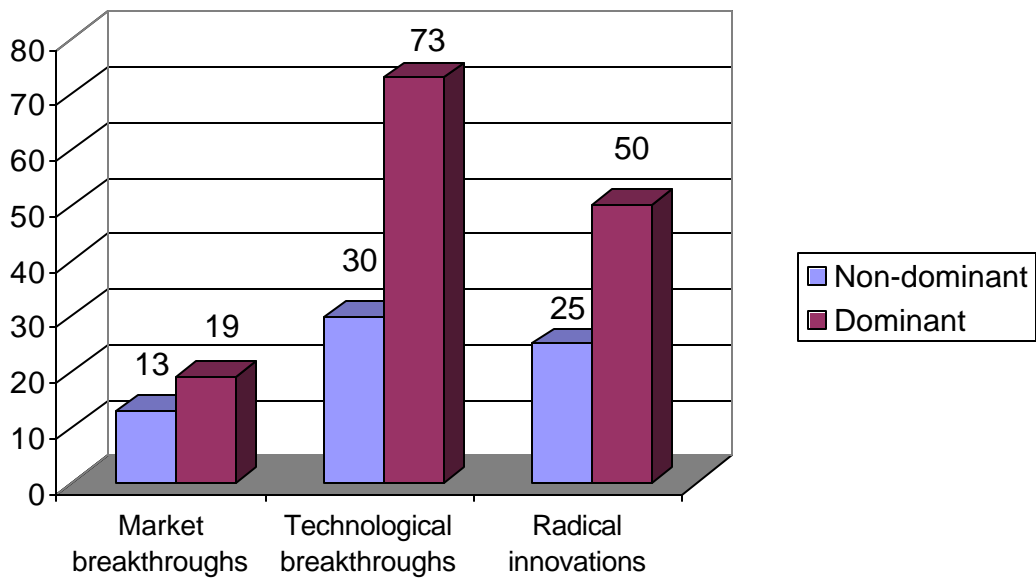


Figure 3

Average Net Present Value of Breakthroughs
for Dominant and Non-Dominant Firms

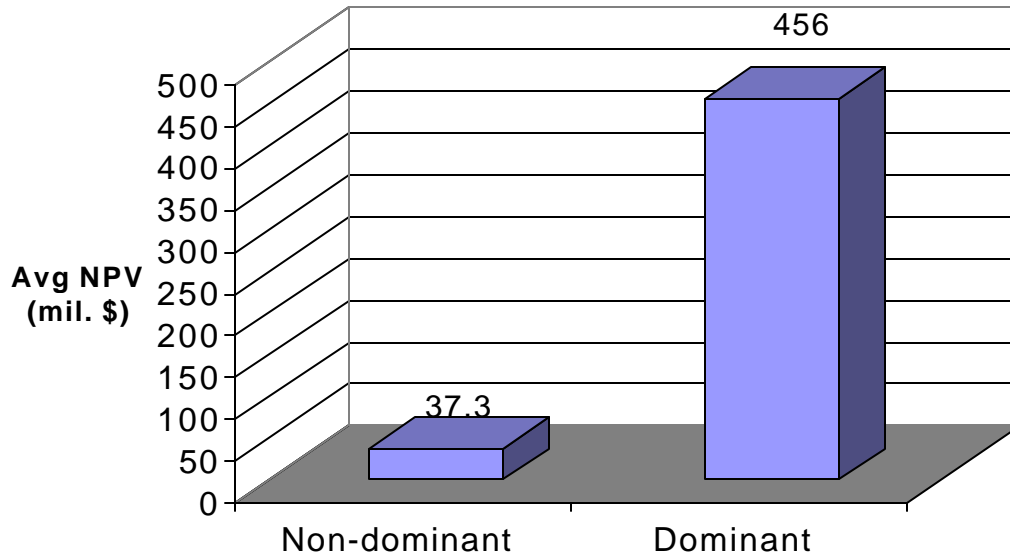


Figure 4

Average Net Present Value for Market Breakthroughs,
Technological Breakthroughs and Radical Innovations

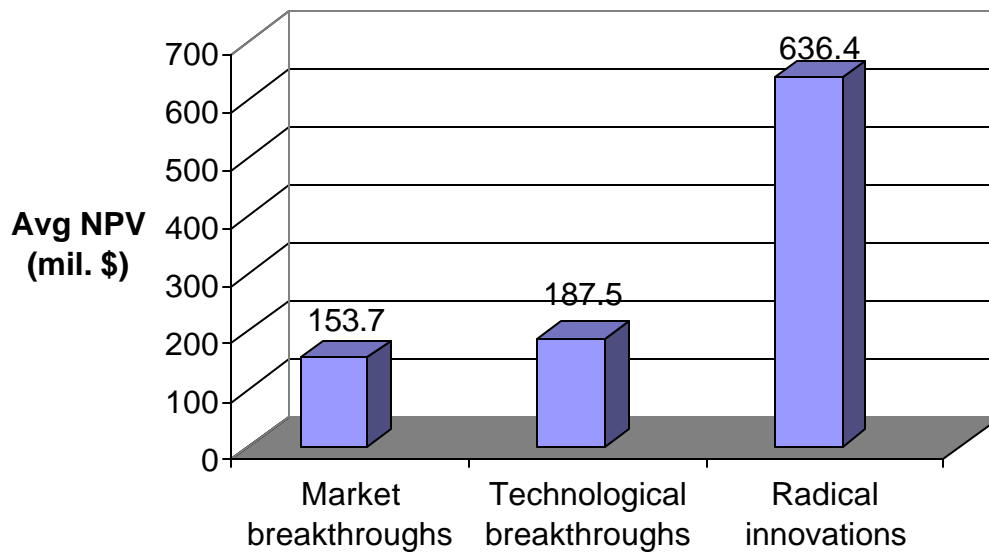


Figure 5

Average Net Present Value of Breakthroughs
for Dominant Firms: High versus Low Product Support

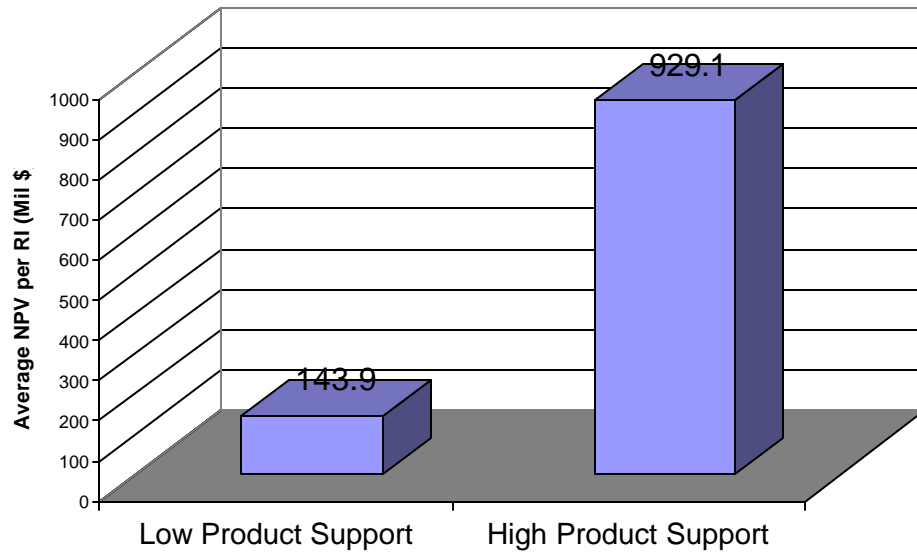
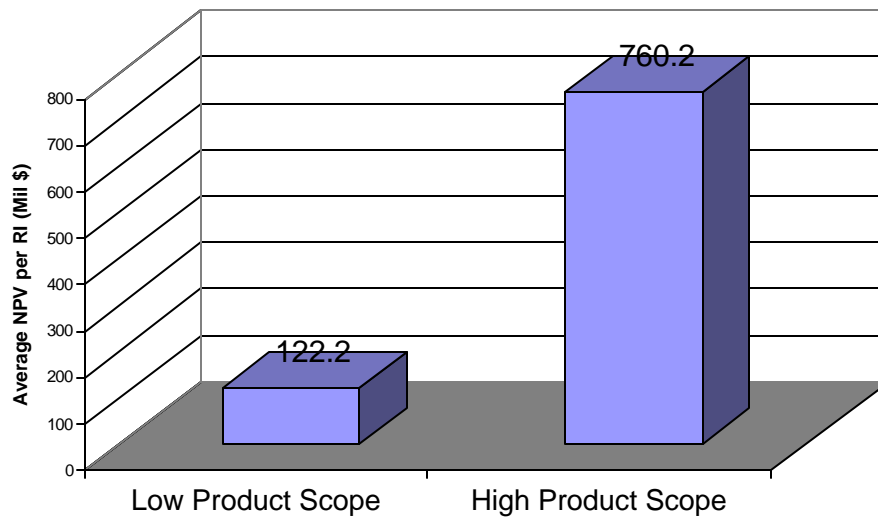


Figure 6

Average Net Present Value of Breakthroughs
for Dominant Firms: High Versus Low Product Scope



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Appendix 1: The Net Present Value of Innovations

Theoretically, the NPV for a particular product is given by:

$$NPV = \sum_t \frac{CF_t}{(1+k)^t} - I_0$$

where: CF_t is the cash flow that the product is expected to generate at time t ;
 k is the required rate of return for that specific project;
 I_0 is the initial investment in the product.

The theoretical appeal of this measure resides in its ability to explicitly reflect variations in financial value predicted by the theoretical constructs on which we have built our arguments: risk and resources. Any firm characteristics or actions that reduce risk are reflected in a lower discount rate, k , which results in higher NPV. In turn, higher levels of resources, such as marketing or technology resources, can 1) increase the size of the cash flows, and 2) decrease the uncertainty of these cash flows, resulting in a lower discount rate and, consequently, a higher NPV.

An estimate of the cash flows expected from the innovation can be obtained from the stock market's assessment of the value that this innovation will add to the value of the firm that introduces it. The theory of efficient markets (Fama 1970) postulates that investors are forward looking and incorporate all publicly available information in a firm's stock price as this information becomes available. Specifically, when a new product approval is announced, investors will adjust the stock price to account for the expected cash flows that the innovation will generate. For pharmaceuticals, the announcement occurs when the FDA gives its final approval for immediate commercialization of the drug.

Measuring NPV

Empirically, we measure NPV by the increase in the market value of the firm over a 3-day window following the announcement associated with the introduction of the new product (we find no indication of information leakage over a two-day period prior to approval). We use a market-

adjusted model to calculate returns. We also use a market model (not reported here) for robustness checks (Brown and Warner 1985). The NPV equation is:

$$NPV = \sum_{t=0}^{t=2} (R_t - R_{m_t}) P_{t-1} Nshares_{t-1}$$

where:

R_t is the rate of return on the firm's stock, calculated as: $R_t = (P_t + d_t) / P_{t-1} - 1$.

P_t is the stock price at time t;

d_t is the dividend per share paid by the firm on day t ($d_t=0$ if no dividend was paid on day t);

R_{m_t} is the equally weighted rate of return of all publicly traded equities on the market;

$Nshares_{t-1}$ is the number of outstanding shares that the firm had the day before the announcement;

$P_{t-1} Nshares_{t-1}$ is the market value of the firm on the day before the announcement.

We collected stock market data for firms traded on US, European and Japanese exchanges.

For non-US firms, we based currency conversions on daily exchange rates collected from DataStream. We used the stock market on which each firm traded as the benchmark to calculate abnormal returns, and conducted robustness checks using the appropriate pharmaceutical indices.

The abnormal change in market value is frequently used to assess the value of firm investments or actions, and has the advantages of comparability and managerial appeal (see Dowdell, Govindaraj, and Jain 1992; Hendricks and Singhal 1996; Klassen and McLaughlin 1996). This measure assigns a unique dollar value to each radical innovation, rather than looking at their effect on a percentage increase in the value of the firm. It therefore allows us to readily compare the value of new products across firms. The dollar value, being an absolute measure, has the additional benefit of ensuring symmetry and consistency between the measures we use for the “who introduces more” and “who gains more” questions.

The NPV measure also has considerable managerial appeal. First, the NPV measure is forward looking, and provides a metric for managers to assess the value of products before a time series of revenue data becomes available. This sets the NPV measure apart from measures such as sales or ROI which are not forward looking, and which capture the performance of a product over a

specific, limited period of time, and only after the fact. Second, the NPV measure is based on excess returns that result from the innovation, net of the expected loss in cash flows from existing products. Since the measure takes into account the extent to which the radical innovation may draw sales from the firm's existing products, it provides a comprehensive metric of the impact of an innovation.

Impact of Information Leakage

A concern common to all event studies that deal with new product announcements is whether any information about the product was incorporated in the stock price prior to the announcement. In our case, the large amount of uncertainty attached to the FDA approval process prevents investors from incorporating a substantial amount of information while the drugs await approval (DiMasi et al. 1991). First, there is uncertainty as to the outcome of the approval process per se, since more drugs are rejected than approved. Second, there is uncertainty attached to the announcement date, also compounded by the fact that it takes an average of 8 years for a drug to go from clinical trials to FDA approval (DiMasi et al. 1991). Third, due to FDA regulations, firms cannot release specific claims for the product before it is approved. Finally, dominant firms are under closer scrutiny by investors and the trade press. Therefore if any information is leaked before the approval of the drug, it is more likely to be about dominant firms. Thus, even if information is incorporated in the stock price prior to the announcement, this effect will decrease the difference in returns at introduction between dominant and non-dominant firms. Our metric is therefore conservative in that it makes support for our hypotheses harder to demonstrate.

Appendix 2: Cost of Capital

The cost of capital is a control variable that accounts for the riskiness of the investments undertaken by the firm (Ross, Westerfield, and Jaffe 1999). High cost of capital is an indication that the firm works on projects perceived by the market as risky. It is not necessarily a proxy for the firm's propensity to produce radical innovations, because riskiness may also be associated with projects such as orphan drugs or drugs that are researched simultaneously by other firms. It is however a measure of investors' expectations for that firm's products. We therefore include it as a control variable in our model. The cost of capital is given by:

$$WACC = K_d \frac{D}{A} (1 - T) + K_e \frac{E}{A}$$

where:

K_d = cost of debt = risk free rate + credit risk premium;

K_e = cost of equity = $R_f + \beta (R_m - R_f)$, where R_f is the risk free rate and R_m is the rate of return on the market;

D = market value of the firm's debt (approximated by book value);

E = market value of the firm's equity (calculated as number of shares outstanding times the market price per share);

A = market value of the firm's assets, approximated as $D+E$;

T = the corporate tax rate.

ENDNOTES

¹ The NDA pipeline is a database of drugs tracked from discovery through preclinical and clinical trial phases, to ultimate approval or rejection by the FDA. It is administered by FDC Reports.

² This median split is conservative. For example, the median number of employees per firm in our sample of radical innovators is 1013 for US firms. The *1997 US Economic Census* reports that less than 3% of the pharmaceutical companies in the US have more than 1000 employees.

³ We also tested a model with main and interaction effects of the marketing and technology support variables. The interaction between marketing and technology support is not significant, and is not included here.