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Sources and Financial Consequences of Radical Innovation: Insights from Pharmaceuticals

Radical innovations are engines of economic growth and the focus of much academic and practitioner interest, yet some fundamental questions remain unanswered. The authors 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: (1) Who introduces a greater number of radical innovations: dominant or nondominant firms? (2) How great are the financial rewards to radical innovations, and how do these rewards vary across dominant and nondominant firms? (3) 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? and (4) Which are more valuable: innovations that incorporate a breakthrough technology or innovations that provide a substantial increase in customer benefits? The authors 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 minority of firms. The financial rewards of innovation vary dramatically across firms and are tied closely to firms' resource base. Firms that provide higher per-product levels of marketing and technology support obtain much greater financial rewards from their radical innovations than do 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 company stock. 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 attempting 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 become the second largest body of literature in industrial organization economics (Cohen 1995). Radical innovation has also been the focus of study in marketing and management research (e.g., Chandy and Tellis 2000; Gatignon and Xuereb 1997; Henderson 1993; Olson, Walker, and Ruekert 1995; Stringer 2000).

Although knowledge of radical innovation has improved considerably during the past 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 thus 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).

Conceptually, although research has explored the antecedents of radical innovations, virtually nothing is known about their performance and financial value. Firms spend billions of research and development (R&D) dollars in trying to create radical innovations. For example, the cost of developing a blockbuster drug that involves a completely new technology has been estimated between $250 million and $350 million (Van Arnum 1998). However, there remain nagging suspicions that the returns to innovation may be scarce (*Fortune* 2000; Golder and Tellis 1993).

All that is known thus far is that radical innovations are more valuable than incremental ones (Chaney, Devinney,

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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 other firms do? Just as there are reasons some firms are better at generating radical innovations, there may be reasons some firms gain more from them. Such reasons, which might include the resources firms own and the ability to protect and leverage new products, have been unexplored thus far.

Methodologically, 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, surveys and retrospective coding, to assess radical innovation. Researchers who use 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 managers' word on whether the firm has introduced or will introduce radical innovations. Therefore, this type of data potentially suffers from self-report bias in measuring innovation (Price and Mueller 1986). Innovation is a desirable outcome, and managers may, consciously or unconsciously, believe there is a 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 which innovation is an explicit corporate goal) are more prone to this bias than others are.

A different kind of bias is possible when retrospective coding is used to assess the radicalness of the innovation: memory and retrospection bias (Golden 1992; Golder and Tellis 1993). Researchers who use 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). However, products that failed may have faded from memory, or their failure may bias the way 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 radical as they truly were on introduction. For example, the sewing machine now seems a prosaic piece of household machinery; however, in 1841, when Barthélémy Thimonnier first introduced the machine, it was a revolutionary product (Cook 1922; Cooper 1976). Upon hearing of the machine, Parisian tailors were so threatened by it that they burned the army tailoring shop where 80 of the machines had been first installed. Thimmonier himself barely escaped with his life (Cooper 1976).

This research attempts to address the preceding outlined conceptual and methodological limitations. We study a broad array of research questions using a unique data set from the pharmaceutical industry that spans ten years (1991–2000). Pharmaceuticals is a knowledge-intensive industry; moreover, innovation is its lifeblood (Gambardella 1995; Scherer 2000). In these respects, pharmaceuticals is similar to other industries (e.g., consumer electronics, fiber optics, 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 research may have implications for other knowledge-intensive and innovation-based industries (see Blundell, Griffith, and Van Reenen 1999). Moreover, pharmaceuticals provide rich sources of data that do not suffer from self-report and retrospective coding concerns and that enable the study of hitherto understudied research questions.

This article addresses the following questions about the sources and financial consequences of radical innovation: (1) Who introduces a greater number of radical innovations: dominant or nondominant firms? (2) How great are the financial rewards to radical innovations, and how do these rewards vary across dominant and nondominant firms? (3) 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? and (4) 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 distinguish 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 attempt 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 related directly 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. Chandy and Tellis (1998) review the literature on radical innovation and note that two common dimensions underlie most definitions of the construct—that is, (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 do. They 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

TABLE 1
Types of Product Innovations

		Customer-Need Fulfillment	
		Low	**High**
Newness of Technology	Low	Incremental innovation	Market breakthrough
	High	Technological breakthrough	Radical innovation

Source: Chandy and Tellis (1998).

technology and the market dimension; it involves a substantially different technology while offering a substantial increase in customer benefits. A *market breakthrough* provides substantially greater benefits than existing products, but its core technology is not significantly new. A *technological breakthrough* uses a substantially different technology than existing products without considerably increasing the benefits to consumers. We adopt Chandy and Tellis's taxonomy of innovations along the technology and market dimensions; this taxonomy is consistent with many other definitions of the "newness" of an innovation (see Garcia and Calantone 2002). We conduct our study in a context that enables us to differentiate empirically among all three types of breakthroughs.

Dominance. We define *dominance* as the level of market power a firm wields (e.g., Scherer 1980). Authors have historically equated dominance with market share (see Szymanski, Bharadwaj, and Varadarajan 1993). However, more recently, some authors 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 revenue 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, because 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, and profits could ensure that firms have adequate financial resources to develop and support innovations. Because firms may vary in the extent to which they dominate in each of these dimensions and because these dimensions may bring different benefits, it is necessary to account for firms' dominance on all three dimensions together (e.g., Pleatsikas and Teece 2001).

Financial value. We assess the financial value of radical innovations using the net present value (NPV) of the future cash flows expected from the innovation (Ross, Westerfield, and Jaffe 1999). The 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, in our context NPV captures the expected value of all future discounted cash flows generated by an innovation. Therefore, it is 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 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 a firm's per-product marketing and technology expenses. 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 breadth and depth of the product portfolio; as such, it reflects the leveraging opportunities of the radical innovation within the firm.

Theoretical Framework

We organize our theoretical arguments around the two fundamental concepts of risk and resources. *Risk* refers to the uncertainty associated with a course of action (e.g., Singh 1986): A product is 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; for a different view, see Kleinschmidt and Cooper 1991), 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 sizable resources to R&D, but they cannot command or even predict the moment when a scientist's mind will conceive of a product beyond the frontier of existing knowledge. Second, at the introduction stage, there is uncertainty associated with the extent and time frame of consumers' adoption of the product (Griffin 1997). In particular, firms involved in radical innovation face both an unknown probability of their products' success (i.e., the likelihood of extracting cash flows from the products) and an unknown extent of their products' success (i.e., the expected magnitude of the cash flows to be extracted from the products).

Which firms can better handle these risks? Firms that can spread risks over a larger asset or product base face

lower costs in raising money to develop or introduce a radical innovation. In addition, 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, which in turn can lower the risks that the firm faces (Lane and Lubatkin 1998). Moreover, at the introduction stage, marketing and organizational resources can help the firm stabilize and increase 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: (1) product support, or the extent to which individual products are supported with marketing and technology resources on introduction (i.e., firms' per-product levels of marketing and technology investments), and (2) product scope, or 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 nondominant 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 find it difficult to adapt and reinvent 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 because such innovations have the potential to decrease the rents such firms extract from their current products (Chandy and Tellis 1998).

If bureaucracy, myopia, and reluctance to change the status quo prevent dominant firms from introducing innovations in general, these should be even stronger deterrents of radical innovations. However, recent empirical research suggests the opposite. Using a retrospective coding of 64 radical innovations in two industries, Chandy and Tellis (2000) conclude that though small firms and new entrants introduced more radical innovations before World War II, this trend has reversed more recently. What explains this change? In the following paragraphs, we propose some reasons that dominant firms may introduce more radical innovations than do other firms.

Radical innovations and the technology necessary to generate them have become increasingly complex, and their undertaking requires sizable resources (e.g., Mowery and Rosenberg 1998; Teitelman 1994). Dominant firms have greater technological, financial, and market-related resources, which put such firms in a better position than nondominant firms to handle the risks associated with radical innovation. Specifically, dominant firms enjoy economies of scale and scope both in R&D (Scherer 1980; Teece 1980) and in marketing (Comanor 1965). Economies of scale in R&D entail a more efficient use of research resources, which in turn enables firms to dedicate a larger fraction of resources to uncertain projects. Economies of scope and the synergies they imply may lead to a greater 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, that is, 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 many 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 do nondominant firms. They have greater access to funds to finance the risky pursuit of radical innovation, and they can spread these risks over a large volume of sales (Arrow 1962; Comanor 1965). In contrast, nondominant firms may not get second chances; their first failure may be their 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 are able to diversify their research portfolios and introduce more of all types of breakthroughs: technological, market, and radical innovations. Although their technical capabilities help dominant firms create technological breakthroughs, the better understanding of the market and customers they obtain 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:

> H_1: Dominant firms introduce significantly more (a) radical innovations, (b) technological breakthroughs, and (c) market breakthroughs than do nondominant 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

Recent research indicates that new product introductions can have a positive impact on 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 greater their financial value is. For example, Chaney, Devinney, and Winer (1991) find that original new products have a greater financial value than updates of existing products, and Klein-

schmidt and Cooper (1991) find that highly innovative products surpass moderately innovative products in terms of their success rate and return on investment.

However, firms may not gain equally from innovation. Our thesis is that it is not only what is introduced that matters, but also who introduces it. Investors value a new product on the basis of how successful they expect the firm to be in commercializing it; specifically, investors evaluate the likelihood of success and the level of success 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 the firm can deploy to sustain and protect the innovation. In particular, dominant firms have greater 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). Because of dominant firms' involvement with previous generations of products, they 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 on the basis of 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 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 such firms' future prospects (e.g., Aldrich and Auster 1986). Although 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 nondominant firms to augment these resources through credit markets. Specifically, nondominant firms face a greater disadvantage than do 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 (i.e., higher interest rates and smaller loans), which can impair growth or even lead to failure after the introduction of a new product (Scanlon 1984).

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

> H_2: Radical innovations, technological breakthroughs, and market breakthroughs introduced by dominant firms are valued more highly than are those introduced by nondominant firms.

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

Aggregate Resources Alone Do Not Tell the Full Story

Previously, we argued that the financial value of a radical innovation depends 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). Therefore, the greatest economic returns go to firms that can extract the most rents from their products. We now highlight the concepts of product support and product scope to argue 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 previously argued that greater marketing and technology resources are a reason the radical innovations introduced by dominant firms are valued more highly than are those introduced by nondominant firms. However, some dominant firms spread these resources over a greater number of products. This suggests that in addition to aggregate resources, it is also necessary to examine the per-product level of resources deployed by the firm, or product support. 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 is well documented (e.g., Cooper and Kleinschmidt 1987; Yeoh and Roth 1999). These investments can build brand equity and create barriers to 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 in turn is 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 the firm 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 also value how well each innovation is protected by patents. This again highlights the importance of viewing resources on a per-product basis in addition to 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. 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 will 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 alone cannot 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 preceding reasoning suggests that investors recognize product support as a source of competitive advantage for firms that introduce radical innovations. Thus:

H_3: Radical innovations, technological breakthroughs, and market breakthroughs introduced by firms with high product support are valued more highly than are those introduced by firms with low product support.

Product Scope

Theory about product sequencing (Helfat and Raubitschek 2000) suggests that the creation of new products depends on both existing products and the underlying path-dependent knowledge and capabilities of a firm. 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.

A greater product scope involves both depth and breadth of expertise. A broad product scope is an indication of greater expertise in dealing with new products in various settings and of 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 as well as 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 breadth) but also is more likely to have the ability to leverage the product (because of depth). This ability to exploit synergies can extend the commercial life of the radical innovation and lead to more successful extensions, thus making the innovation more valuable.

A narrow product scope may also signal to investors that the firm has a deeply embedded knowledge set and that its core competence, though well defined, is limited and associated with a certain rigidity in dealing with projects outside the scope of the core competence (Leonard-Barton 1992). Such a firm may lack either 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 of the firm's narrow scope, investors may fear that the firm has limited experience in the new domain. This assessment would be reflected in the stock market's evaluation of the product. Thus:

H_4: Radical innovations, technological breakthroughs, and market breakthroughs introduced by firms with high product scope are valued more highly than are those introduced by firms with low product scope.

Are All Breakthroughs the Same?

At first, it may appear that market breakthroughs are more highly valued by investors than are technological breakthroughs, because 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 are technological breakthroughs. Thus, the economic rents that the firm can 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 in 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.

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). Thus:

H_5: Technological breakthroughs are valued more highly than are market breakthroughs. Radical innovations are valued the highest.

Overall, our hypotheses indicate our search for insights into the sources of radical innovations and the financial gains they generate. Drawing on marketing, strategy, and industrial organization, the hypotheses highlight the role of risk and resources in determining the sources and consequences of radical innovation. Any tests of the preceding hypotheses should take into account 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 we used, including several novel features that can help alleviate some of the methodological problems of prior research.

Method

This section presents an overview of the data and empirical context of the article and describes how we translated each of our conceptual variables into empirical measures and how we specified the models in the empirical analysis.

Data and Empirical Context

To test our hypotheses, we need (1) a comprehensive sample of radical innovations, (2) objective measures of the radicalness of innovations, (3) a measure of the financial value of innovations at the time the innovation is introduced, and (4) a context with adequate variation in resources across firms but that 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, researchers have 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 enable us to study their effects 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).

Restriction of 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. A comparison of Viagra to microwave ovens, for example, 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 enables 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: therapeutical potential and chemical composition. On the basis of their therapeutical potential, drugs are classified into two classes: priority review drugs, which represent a therapeutical advance over available therapy, and standard review drugs, which have therapeutical qualities similar to those of an already marketed drug. On the basis of their chemical composition, drugs are classified as either new molecular entities (NMEs) or drugs that are either new formulations or have new indications of use. The NMEs are the most technologically advanced products, because they are based on an active ingredient that has never been marketed before. Table 2 presents the FDA definitions of these categories and 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 therapeutical potential dimension corresponds to our customer benefits dimension, and 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 greater customer benefits than do existing products. A market breakthrough provides substantially greater 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 greater customer benefits. On the basis of these definitions, we classify product innovations as follows:

- radical innovations: priority review and NME,
- market breakthroughs: priority review and non-NME, and
- technology breakthroughs: standard review and NME.

Our sample is based on a census of innovations from 1991 to 2000 that we obtained from the NDA Pipeline.[1] 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 and stock market data). We eliminated 17 observations from the analysis because of confounding effects of firm announcements unrelated to the approval of the drug. Specifically, we checked for

[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 F-D-C Reports.

TABLE 2
FDA Definitions and Operationalization of Innovations

FDA Definitions

Chemical Composition	NME	An active ingredient that has never been marketed in the United States.
	Update	A drug that is a new formulation, a new dosage of existing components, or a commercialized drug that has a new usage.
Therapeutical Potential	Priority review drug	A drug that appears to represent an advance over available therapy.
	Standard review drug	A drug that appears to have therapeutical qualities similar to those of an already marketed drug.

Operationalization of Innovations

		Therapeutical Potential	
		Standard Review	**Priority Review**
Chemical Composition	Update	Incremental innovation	Market breakthrough
	NME	Technological breakthrough	Radical innovation

equity offerings, earnings, dividends, and mergers and acquisitions announcements made in the time window used in the NPV measure that could have distorted the abnormal returns.

The 255 breakthroughs in our sample were introduced by 66 publicly traded firms. The total number of new products introduced by these firms from 1991 to 2000 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 we excluded from our sample are from divisions of large conglomerates, private firms, firms that were no longer in business in 2000 (and for which financial data are unavailable), or 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 nondominant firms introduced are roughly equal in number to the dropped innovations that dominant firms introduced.

The 66 firms in our sample have headquarters in seven countries: the United States, the United Kingdom, France, Belgium, Switzerland, Germany, and Japan. Four of the firms in the data set were acquired before 2000. For those firms, we included accounting data until the year of their acquisition; we treated data in the remaining years 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 that is composed of 255 breakthroughs introduced by 66 firms over a ten-year period. We therefore must analyze an unbalanced panel of data. We also must choose appropriate econometric models to accommodate the two dependent variables of interest (the number and the financial value of radical innovations) and to account for any unobserved heterogeneity due to firm-specific effects.

As we noted previously, 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 multifaceted nature of dominance but also its relationship to firm resources, one of our key theoretical constructs. There-

TABLE 3
Description of the Census of Radical Innovations in the Pharmaceutical Industry from 1991 to 2000

Nature of Breakthroughs	Details	Detailed Count	Count
Used in the sample (introduced by public firms)		226	226
Introduced by public firms in the sample, but data on one of the three components of dominance or the stock market were 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 Nestlé	7	
	Division of Procter & Gamble	1	
	Division of Sigma-Tau Pharma (Italy)	1	
	Division of Snow Brand Milk Products (Japan)	1	
Introduced by firms that were acquired before 2000 and for which financial data were 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 were 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'Oréal and Nestlé	1	
Total		380	380

TABLE 4
Variables and Data Sources Used in the Study

Conceptual Variable	Measured Variable	Data Source
Dominance	f(sales, assets, profits)	•Compustat, Thomson Datastream, Standard & Poor's
Type of breakthroughs	Market breakthrough: FDA priority review Technological breakthrough: FDA NME classification Radical innovations: NMEs that are also priority review drugs	•NDA Pipeline •"The Pink Sheet"
Value of radical innovations	NPV	•Center for Research in Security Prices •Datastream
Marketing support (product support)	Sales force/number of new products; number of sales calls/number of new products; detailing dollars/number of new products; advertising expenditures	•Verispan (Scott Levin Inc.) •NDA Pipeline •Schonfeld & Associates
Technology support (product support)	Citation-weighted patents/number of new products; R&D expenditures/number of new products	•U.S. Patent and Trademark Office database •Compustat
Product scope	Entropy × number of new products	•NDC directory •Freedom of Information database of drugs
Original source of innovation	Dummy for inventor	•Pharmaprojects •"The Pink Sheet" •LexisNexis
Riskiness of projects undertaken by the firm	Cost of capital	•Lehman Brothers Fixed Income Research Program •Datastream, etc.

fore, a dominant firm is more than a large firm; it is a profitable firm with resources.

Because all our data are 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 Radical Innovations (H_1)

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: It is nonnegative (i.e., a firm cannot have –5 innovations), and it involves integers (i.e., a firm cannot have 2.35 innovations). Ordinary least squares is inappropriate for count data. Moreover, the data extend over multiple years for the same firms; that is, they form a time-series cross-sectional panel. In the tradition of Blundell, Griffith, and Van Reenen (1999) and Hausman, Hall, and Griliches (1984), among others, we account for these properties using a Poisson model to test H_1. The basic Poisson probability specification is

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

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

We model the parameter $\tilde{\lambda}_{it}$ 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. Although we do not formally hypothesize a relationship between radical innovativeness and the firm's incremental innovation output, this model enables us to explore whether radical innovations are "accidents" or part of a more substantial innovation output at the firm level. We include a dummy for country (U.S./non-U.S.) in the model to account for any effects in valuation that may exist between U.S. and non-U.S. firms.

The panel nature of the data also enables us to control for firm-specific unobserved heterogeneity. We use a ran-

dom effects model and specify the Poisson parameter $\tilde{\lambda}_{it}$ as follows:

$$(2)\quad \tilde{\lambda}_{it} = \lambda_{it}\tilde{\alpha}_i = \exp(X_{it}\beta + \mu_0 + \mu_i)$$

$$= \exp(\beta_1 \text{Dominance}_{it} + \beta_2 \text{No.Prod}_{it} + \beta_3 \text{No.Patents}_{it} + \beta_4 \text{Country}_i + \nu\mathbf{Year} + \mu_0 + \mu_i),$$

where

$\tilde{\alpha}_i$ = a random firm-specific effect;
No.Prod_{it} = control variable, the number of incremental products introduced in the same year with the radical innovation;
No.Patents_{it} = control variable, the number of patents applied for in the year the radical innovation was introduced;
Country_i = control variable, a dummy that has a value of 1 if the drug is introduced by a firm with U.S. headquarters and a value of 0 otherwise;
Year = a matrix of dummies for year of introduction;
μ_i = the unobserved firm-specific effect; and
μ_0 = the overall intercept.

The Poisson probability specification becomes

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

and the joint density is

$$(4)\quad P(n_{i1}, ..., n_{in_i}/X_i, \mu_i) = \left(\prod_{t=1}^{n_i}\frac{\lambda_{it}^{n_{it}}}{n_{it}!}\right)\exp\left[-\exp(\mu_i)\sum_{t=1}^{n_i}\lambda_{it}\right]\exp\left(\mu_i\sum_{t=1}^{n_i}n_{it}\right).$$

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 a random-effects) specification of unobserved heterogeneity. We report the results of these checks in a subsequent section.

Measures and Model for the Test of Who Gains More from Radical Innovations (H_2–H_5)

Measuring innovation valuation. Srivastava, Shervani, and Fahey (1998) argue 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 NPV, which captures the expected value of all future discounted cash flows generated by the innovation (Fisher 1965; Ross, Westerfield, and Jaffe 1999). We discuss how NPV is measured and its theoretical and managerial implications in Appendix A.

Measuring product support. Product support has two components: marketing support and technology support. We assessed marketing support on the basis of investments in the firm's sales force. (In a subsequent section, we report results from a measure of product support that also includes direct-to-consumer advertising.) Because sales force expenditures are considered the most important promotional expenditures in the pharmaceutical industry (e.g., Yeoh and Roth 1999), we obtained three measures of firm investments in the sales force: (1) the size of the sales force, (2) the number of sales calls placed by the salespeople, and (3) the amount of dollars that the firm has spent on its sales force. We purchased the data from Verispan, a marketing research firm that tracks the performance and investments made by pharmaceutical firms. We computed the relative size of these marketing investments to the number of new products introduced per year. Specifically, we operationalized marketing support by using the factor scores from a principal component analysis on the relative measures of sales force. Similarly, we assessed technology support on the basis of the firm's R&D expenditures and the patent support that the firm's products enjoy. We used citation-weighted patents in light of recent research that shows that citation-weighted patents are a better measure than unweighted patents of a firm's ability to appropriate returns from its innovations (Hall, Jaffee, and Trajtenberg 2000). We computed the relative size of the R&D investments and citation-weighted patent stocks to the number of new products introduced per year. We then operationalized technology support using the factor scores from a principal component analysis on the relative R&D and patents measures. We measured product support as the sum of the (standardized) marketing and technology support variables.

Measuring product scope. 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 and the depth of the multifaceted knowledge that arises from introducing many innovations across multiple product categories. We therefore needed to modify existing measures of diversification to account for not only the breadth of the product portfolio but also its overall depth. One of the most commonly used measures of diversification is entropy (Varadarajan 1986):

$$(5)\quad E = \sum_{j=1}^{n} p_j \ln\left(\frac{1}{p_j}\right),$$

where

$p_j = P_j/P$, the fraction of the firm's products in the jth product category relative to its overall product portfolio;
P_j = 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; and
P = the firm's overall number of products at time t.

The entropy measure does not differentiate among firms that have the same breadth of product portfolio but different depths. A firm with 5 products, 1 in each of five different product categories, has the same entropy as a firm with 500 products, 100 in each of five different product categories. Our conceptual definition of scope, as we noted previously, also takes into account the depth of the product portfolio, because 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:

$$(6)\ \text{Product scope} = E \times P = \left[\sum_{j=1}^{n} \frac{P_j}{P} \ln\left(\frac{P}{P_j}\right)\right] P = \sum_{j=1}^{n} P_j \ln\left(\frac{P}{P_j}\right).$$

Quantification of 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 are from the National Drug Code (NDC) directory database. The NDC directory 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 FDA-approved drugs available in the United States but also classifies the drugs into 21 major therapeutic categories, which in turn are divided into subcategories. We use these major therapeutic categories to define each firm's product categories and to construct product scope as in Equation 6. Our data cover 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 H_2–H_5

To test H_2–H_5, we estimated the following model (e.g., Baltagi 2001; Dutta, Narasimhan, and Rajiv 1999; Geroski, Machin, and Van Reenen 1993):

$$\begin{aligned}(7)\quad NPV_{ikt} = {} & \beta_0 + \beta_1 Dominance_{it} + \beta_2 ProductSupport_{it} \\ & + \beta_3 ProductScope_{it} + \beta_4 RI_{kt} + \beta_5 MB_{kt} \\ & + \beta_6 Licensed_{kt} + \beta_7 WACC_{it} + \beta_8 Country_i \\ & + \beta_9 NRI_{it} + \gamma \mathbf{Year} + \lambda \mathbf{Category} + \zeta_i + \eta_{it},\end{aligned}$$

where

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

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

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

NRI_{it} = 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; and

ζ_i = the unobserved firm-specific effect.

Results

Who Introduces More Radical Innovations?

A major concern in assessing the sources of radical innovation is distinguishing between who invented the innovation and who introduced it. It is conceivable that entrepreneurs develop a radically new product but do not have the means to commercialize it and thus sell it to a larger organization. Because dominance is a central variable in our study, it is especially important to account for this possibility. The FDA data indicate only to whom the approval to market the drug was granted, and thus we also needed to determine the original source of the innovation, or its inventor. A comprehensive search that included "The Pink Sheet" (a detailed newsletter about pharmaceutical and biotechnology products, published by F-D-C Reports), the Pharmaprojects database of pharmaceutical projects, and trade press articles published while the drugs were in development enabled us to determine that the original inventors introduced 193, or approximately 75%, of the 255 breakthroughs studied; 62 breakthroughs were licensed or bought from other firms. Only 25% of the radical innovations introduced by dominant firms were licensed or acquired before FDA approval, and the rest were invented in-house by the firms. In addition, because the Bayh-Dole Act (35 U.S.C. §§ 200–212) sets up considerable incentives in the pharmaceutical industry for commercializing university research, we also used the Pharmaprojects database to determine how many of the drugs in our database were invented at universities. We found that only 4 of the 255 drugs in our data set were invented at universities. We further address the issue of invention versus product acquisition in analyses later in this section.

H_1 suggests that dominant firms introduce more radical innovations and more breakthroughs than nondominant firms do. Dominance is significant as a continuous variable in the Poisson model that predicts the count of innovations ($e^{\beta} = 1.58$; $p < .001$; for results, see Table 5). For ease of exposition, the coefficients for the time dummies are not included in Table 5. 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 ($e^{\beta} = 1.02$; $p < .001$). The number of patent applications submitted by the firm, a common measure of innovativeness previously used in the literature, was not significant ($p = .44$). Even after we accounted for whether the innovation was invented in-house or acquired, dominant firms still introduce more radical innovations. There is no significant difference in the proportion of licensed innovations introduced by dominant versus nondominant firms (likelihood ratio $\chi^2 = .51$, $p = .48$). We obtained similar results with the same level of significance if we used (1) firm size (operationalized in terms of number of employees) rather than the measure of dominance reported herein; (2) marketing and

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

	Incidence Rate Ratio (e^b)
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	.95
Log-likelihood	–383.12
Wald χ^2	116.72*

*$p < .01$.
Notes: Dependent variable is number of breakthrough innovations.

technology support measures computed using the standardized sum of their components, rather than factor scores (for details, see Sorescu, Chandy, and Prabhu 2003); and (3) a fixed-effects specification of firm-specific unobserved heterogeneity rather than the random-effects specification reported herein. We also used a negative binomial model of counts rather than a Poisson model. The overdispersion parameter is not significantly different from zero; thus, the negative binomial distribution is equivalent to the Poisson distribution.

To better understand the difference between dominant and nondominant 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 innovators.[2] Figure 1 suggests that dominant firms introduce more than twice as many radical innovations and breakthroughs than do nondominant 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 greatest difference arises for technological breakthroughs, which 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 greatest number of breakthrough innovations. It is notable that the top 15 most innovative firms introduced 161 breakthrough innovations, more than half of all breakthrough innovations introduced in the entire 1991–2000 period.

[2]This median split is conservative. For example, the median number of employees per firm in our sample of radical innovators is 1013 for U.S. firms. The 1997 U.S. Economic Census (U.S. Census Bureau 1997b) reports that less than 3% of the pharmaceutical companies in the United States have more than 1000 employees.

FIGURE 1
Number of Breakthroughs Introduced by Dominant and Nondominant Firms

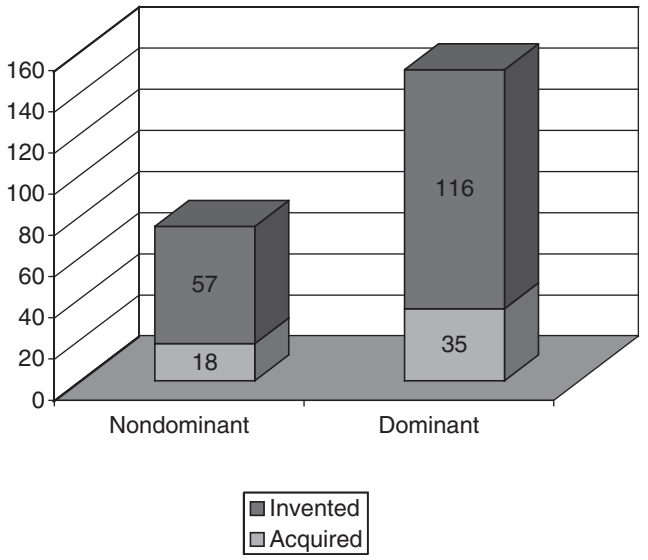
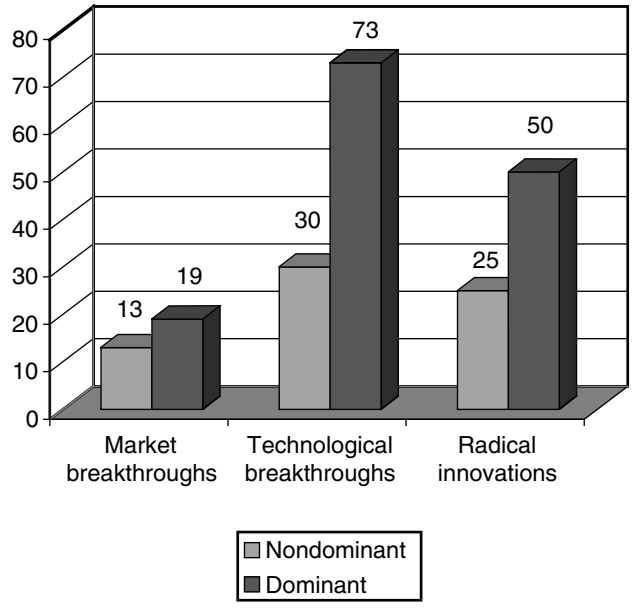


FIGURE 2
Types of Breakthroughs Introduced by Dominant and Nondominant Firms



Results in Table 6 further indicate that firms that 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.

TABLE 6
Firm-Level Innovation Ranking and Innovation Counts, 1991–2000

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

What Is the Impact of Product Support and Product Scope on Radical Innovations?

H_2 argues that dominant firms gain more from radical innovation. H_2 is supported; results suggest that though a new product introduced by a dominant firm is valued at about $456 million, it is only valued at about $37 million if it is from a nondominant firm (Figures 3 and 4). This difference is significantly different from zero ($p < .01$). Again, if firm size (number of employees) is used rather than the composite measure of dominance, the differences between dominant and nondominant firms are even more pronounced. Dominance is also significant as a continuous variable in all three random-effects models that we tested. A ranking of the highest NPV drugs is presented in Table 7.

To estimate the effect of product support, we first ran separate principal component analyses on the three sales force 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 computed product support as the sum of marketing and technology support. The standardized coefficients for product support ($\beta = .38$; $p < .001$) and product scope ($\beta = .26$; $p < .05$) are significant; addition of these variables to the model more than doubles the R^2. Therefore, H_3 and H_4 are supported: Greater 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.)

Furthermore, product support and product 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 ($p < .05$) and scope ($p < .01$). We report the results for product scope using a 17-year rolling window, but significance is

FIGURE 3
Average NPV of Breakthroughs for Dominant and Nondominant Firms

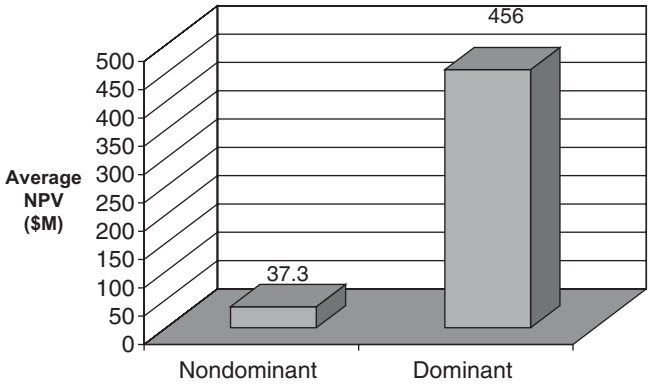


FIGURE 4
Average NPV for Market Breakthroughs, Technological Breakthroughs, and Radical Innovations

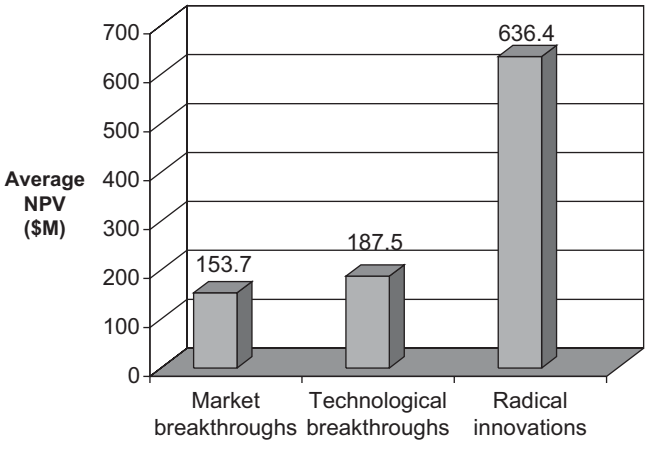


TABLE 7
Ranking of Highest NPV Drugs, 1991–2000

Drug Name	Drug Class	Company	Approval Date	Innovation Type	Licensed	NPV (in $M)
Singulair	Respiratory; pulmonary asthma/antiasthmatic	Merck	February 20, 1998	Technological breakthrough	No	6981.7
Tikosyn	Cardiovascular; arrhythmia/ antiarrhythmic	Pfizer	January 10, 1999	Technological breakthrough	No	6313.5
Viagra	Gynecological; genitourinary impotence	Pfizer	March 27, 1998	Radical innovation	No	6189.9
Rapamune	Immunology/autoimmune disease	Wyeth-Ayerst	September 15, 1999	Radical innovation	No	5745.0
Mylotarg	Cancer; blood cancer; leukemia	Wyeth-Ayerst	May 17, 2000	Radical innovation	No	5552.9
Glucovance	Metabolic disorders; diabetes; diabetic complications	Bristol-Myers Squibb	July 31, 2000	Technological breakthrough	Yes	5428.8
Rebetron	Infectious diseases and viral diseases; antiviral hepatitis	Schering-Plough	June 3, 1998	Market breakthrough	Yes	4910.0
Aggrastat	Cardiovascular	Merck	May 14, 1998	Radical innovation	No	4807.4
Relenza	Infectious diseases and viral diseases; antiviral influenza	GlaxoSmithKline	July 27, 1999	Radical innovation	Yes	4112.7
Temodar	Cancer, brain cancer	Schering-Plough	August 11, 1999	Radical innovation	Yes	3281.4

TABLE 8
Results: Financial Value of Innovations

	Model 1 (N = 195)[a]	Model 2 (N = 117)[a]	Model 3 (N = 117)[a]
Dominance	.16**	.51**	.50**
Radical innovation	.17**	.31***	.30***
Market breakthrough	.06	.11	.11
Product support	—	.38***	—
Marketing support	—	—	.34***
Technology support	—	—	.49**
Product scope	—	.26**	.23*
Number of breakthroughs	.04	.15	.15
Cost of capital	.10	.35***	.33**
Diuretics	.17**	.54	.50
Country	–.09	.06	.04
Licensed	–.06	–.13	–.14
Wald χ^2	23.55	48.37	48.55
(p-value)	(.0027)	(<.0001)	(<.0001)
R^2 within	.09	.29	.28
R^2 between	.14	.24	.24
R^2 overall	.11	.31	.31

*p < .10.
**p < .05.
***p < .01.
[a]Standardized coefficients.

FIGURE 5
Average NPV of Breakthroughs for Dominant Firms: High Versus Low Product Support

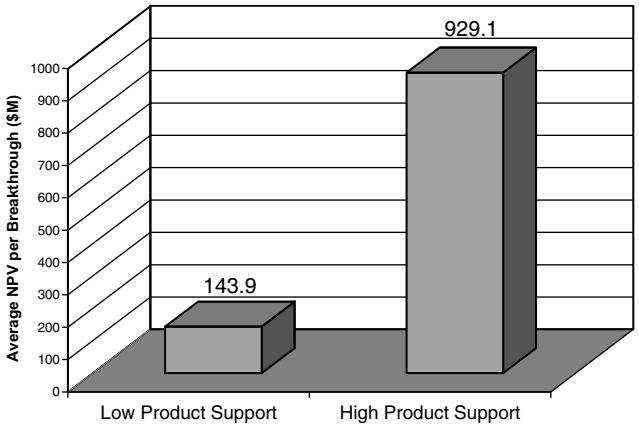
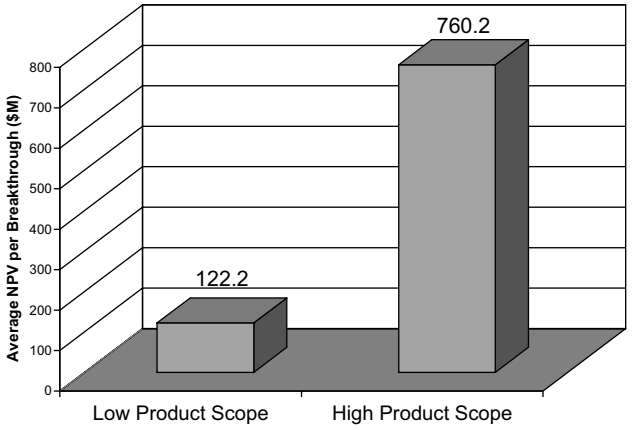


FIGURE 6
Average NPV of Breakthroughs for Dominant Firms: High Versus Low Product Scope



also maintained if we use a 14- or 21-year window. We controlled 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 did not include the nonsignificant therapeutic class and year dummies in the final model. We also checked whether the market reaction to the drugs introduced by biotechnology firms was different from the reaction to drugs introduced by all other firms. We found no significant differences between the two types of firms. To further explore the relationship among dominance, support, and scope, we present results from four additional analyses. First, we examined 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 (β = .34; p < .001) and technology support (β = .49; p < .05), have a significant, positive effect on NPV. Furthermore, including the two components maintains the significance of the other relevant independent variables.[3]

[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.

Second, we expanded the operationalization of product support by including advertising as an additional component of marketing support. In recent years, pharmaceutical firms have viewed direct-to-consumer advertising as an increasingly important marketing expenditure. However, we were able to collect advertising data for only 16 firms in our sample, corresponding to 85 innovations. We found that advertising expenditures are highly correlated with the other marketing variables: The correlation between advertising and dollars spent on sales calls is .80 ($p < .001$) and that between advertising and number of calls is .83 ($p < .001$). The sign of the coefficients and their significance levels are maintained when we added advertising to the marketing support variable in our random-effects model (see Table 9). We report the results of this analysis separately, because advertising data are available only for a limited subsample of firms and because 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 firms with high dominance and high product support. The NPV for high dominance, high support is significantly greater ($p < .05$) than the NPV for high dominance, low product support. In addition, the NPV for low dominance, high support is not significantly different from high dominance, low support ($p = .84$). Thus, investment in product support may provide nondominant firms with a means to equalize their NPV position relative to low-support dominant firms.

Fourth, we checked whether nondominant firms provide more monetary incentives to their salespeople. In theory, such firms could compensate for small sales forces by spending more per sales person and per sales call. Empirically, we found that the average detailing expenses per salesperson from 1991 to 2000 were $116,000 and $79,000 for dominant and nondominant firms, respectively. The dominant firms in our sample spent an average of $132 per sales call, whereas nondominant firms spent an average of $129. Overall, these richer measures provide additional evidence of dominant firms' resource advantages.

TABLE 9
Financial Value of Innovations: Results Incorporating Advertising

	Model 1 (N = 85)[a]	Model 2 (N = 85)[a]
Dominance	.63**	.60*
Radical innovation	.38***	.38**
Market breakthrough	.00	–.02
Product support	.48***	—
Marketing support	—	.49***
Technology support	—	.47*
Product scope	.37**	.39**
Number of breakthroughs	.12	.14
Cost of capital	.51***	.56***
Diuretics	.25	.15
Country	.45**	.44*
Licensed	–.10	–.09
Wald χ^2	51.17	49.20
(p-value)	(<.0001)	(<.0001)
R^2 within	.38	.38
R^2 between	.44	.43
R^2 overall	.40	.40

*$p < .10$.
**$p < .05$.
***$p < .01$.
[a]Standardized coefficients.

Are Different Breakthroughs Valued Differently?

H_5 maintains that technological breakthroughs are valued more highly than market breakthroughs, and radical innovations will be valued most. H_5 is partially supported: Radical innovations are valued significantly more than either technological or market breakthroughs (see Table 8). However, we did not find any significant differences between the financial valuation of technological and market breakthroughs. Although technological breakthroughs have a higher mean value, their variance is also higher, highlighting their riskiness. Figure 4 presents the NPV 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 beyond the short-term ones (p-values for the tests of zero one-year and two-year buy-and-hold abnormal returns were greater than .10). Moreover, the results show no significant differences between dominant and nondominant firms in the long run. 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 on request 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 another. 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 to entry that their larger counterparts impose. If this is true, then making generalizations is especially imprudent. Some commonly studied industries in the innovation context are household appliances, electronic computer manufacturing, fiber-optic cable manufacturing, and semiconductor manufacturing. As data from the U.S. Economic Census (U.S. Census Bureau

1997a) show, the pharmaceutical industry is less concentrated than most of these industries (see Table 10).

Another cause for concern is that nondominant firms are disadvantaged because of the long process involved in obtaining FDA approval for innovations; nondominant 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 (21 U.S.C. § 301 et seq.) 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 will collect economic rents from their drugs beyond their initial R&D investments (Scherer 2000). Indeed, several authors have noted that firms in the pharmaceutical industry enjoy a relatively high level of appropriability of the returns from innovations (Gambardella 1995). Firms also have greater access to venture capital than do those in many other industries (Fugazy 2002). All these factors could help protect the investments of nondominant firms and help explain why firms with fewer than 100 employees account for 73.83% of all pharmaceutical firms (U.S. Census Bureau 1997b). The long approval process does not appear to hinder the participation of nondominant 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 in making incremental changes to existing products but inept in 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 do nondominant firms. Moreover, nondominant firms suffer from double jeopardy in the radical innovations game; not only do they introduce fewer 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 greater 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 often-held belief that new, discontinuous technologies signal the swan song of dominant firms because they do not 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 nondominant 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 may be seeking economies of scope to increase their productivity, innovativeness, and profitability.

Do our results mean that small, nondominant firms are doomed in their quest for radical innovations? Not necessarily. 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, thus offering a means for nondominant 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 gain as much (or more) from its radical innovations as a dominant firm that fails to support its products adequately.

Our findings also offer managers of nondominant firms an indication of how much their breakthrough innovations are worth, both to them and to a dominant firm (or a firm with greater marketing expertise) that would be interested in

TABLE 10
Industry Concentrations

Industry	Prior Research	Value of Shipments Accounted by the Largest 20 Companies[a] (%)	Herfindahl-Herschmann Index for the 50 Largest Companies[a]
Pharmaceuticals	Dekimpe and Hanssens (1999), Gatignon, Weitz, and Bansal (1990), Rangaswamy and Krishnamurthi (1991)	69.7	441.5
Household appliances	Sultan, Farley, and Lehmann (1990), Chandy and Tellis (2000)	82.7	839.8
Electronic computer manufacturing	Chandy and Tellis (1998), Eisenhardt and Tabrizi (1995)	90.0	658.2
Semiconductors	Dutta, Narasimhan, and Rajiv (1999)	62.1	688.7

[a]Available from the U.S. Census Bureau (1997a).

marketing their products. The substantial differences in valuation uncovered in this analysis leave considerable room for licensing activities that would benefit both the small inventors and the large firms that are better positioned to commercialize the inventions.

In a marketplace with intense competitive forces, radical innovations arguably are the last type of product for which the old belief "make a good product and customers will beat a path to it" is still applicable. This article 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 on the resources of the firm that introduces the innovation.

Appendix A
The NPV of Innovations

Theoretically, the NPV for a particular product is given by

$$\text{(A1)} \qquad NPV = \sum_{t} \frac{CF_t}{(1+k)^t} - I_0,$$

where

CF_t = the cash flow that the product is expected to generate at time t,
k = the required rate of return for that specific project, and
I_0 = 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 increase the size of the cash flows and 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 the 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 three-day window after the announcement associated with the introduction of the new product (we find no indication of information leakage over the two-day period before 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

$$\text{(A2)} \qquad NPV = \sum_{t=0}^{t=2} (R_t - R_{m_t}) P_{t-1} Nshares_{t-1},$$

where

R_t = rate of return on the firm's stock, calculated as $R_t = [(P_t + d_t)/P_{t-1}] - 1$;
P_t = stock price at time t;
d_t = the dividend per share paid by the firm on day t ($d_t = 0$ if no dividend was paid on day t);
R_{mt} = the equally weighted rate of return of all publicly traded equities on the market;
$Nshares_{t-1}$ = the number of outstanding shares that the firm had the day before the announcement; and
$P_{t-1}Nshares_{t-1}$ = market value of the firm on the day before the announcement.

We collected stock market data for firms traded on U.S., European, and Japanese exchanges. For non-U.S. 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 indexes.

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 instead of examining the innovations' effect on a percentage increase in the value of the firm. It therefore enables us to compare the value of new products across firms. The dollar value, as 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 return on investment, which are not forward-looking and capture the performance of a product over a specific, limited period of time, and then 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. Because the measure takes into account the extent to which the radical innovation can 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 before 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 about the outcome of the approval process per se, because 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 eight years for a drug to proceed from clinical trials to FDA approval (DiMasi et al. 1991). Third, because of 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 drug's approval, it is more likely to be about dominant firms. Thus, even if information is incorporated in the stock price before the announcement, the effect will decrease the difference in returns at introduction between dominant and nondominant firms. Our metric is therefore conservative because it makes support for our hypotheses more difficult to demonstrate.

Appendix B
Cost of Capital

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. However, it is 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

$$\text{(A3)} \qquad \text{WACC} = K_d \frac{D}{A}(1 - T) + K_e \frac{E}{A},$$

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 × market price per share);
A = market value of the firm's assets, approximated as D + E; and
T = corporate tax rate.

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