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Drivers of Technological Novelty and Superior Customer-Need Fulfillment in New Product Development

Stefan Wuyts and Shantanu Dutta

In technology-intensive industries, firms strive for novelty and superior customer benefits. Here, researchers examine how internal and external knowledge drives these key dimensions. Their findings suggest that firm investments in developing unique knowledge resources and diverse R&D portfolio agreements will pay off.

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Report Summary

Two key dimensions characterize radical product innovation: technological novelty and superiority in fulfilling customer needs. Despite their importance, there is little research investigating the drivers of these two dimensions.

In this study, Wuyts and Dutta investigate the factors that generate technologically novel products and those that generate products that significantly improve their fulfillment of customers' needs. They focus on the roles of internal knowledge development and external knowledge sourcing (through a diverse portfolio of R&D agreements) in new product development in the pharmaceutical industry.

They find that the development of a unique, internal knowledge base and the development of a diverse portfolio of R&D agreements offer alternative routes toward developing technologically novel products. They do not offer alternative paths to the development of products superior in customer-needs fulfillment. That is, while a diverse portfolio aids directly along the dimension of superiority in customer-needs fulfillment, a sole focus on a unique, internal knowledge base does not. However, when complemented by a diverse portfolio of agreements, a unique, internal knowledge base does aid in generating products superior in customer-need fulfillment (presumably because the diverse portfolio gives informed directions to the development of the internal knowledge base).

Interestingly, the authors also find that experience with developing products superior in customer-need fulfillment aids in the subsequent generation of both superior and technologically novel products. However, experience with developing technologically novel products does not affect the likelihood of generating products along either of the two dimensions. This finding refutes the notion that firms at the forefront of technological progress can effectively identify new application areas for superior customer benefits.

Although the authors focus on the pharmaceutical industry, their findings extend to other industries—such as IT, semiconductor, and telecommunications—where managers must cope with a fast technological pace and uncertainty. ■

Introduction

There is rich literature on radical product innovation in diverse disciplines such as economics (Henderson 1993), management science (Dewar and Dutton 1986; Iansiti and West 1997), and marketing (Chandy and Tellis 1998, 2000; Wind and Mahajan 1997). Despite substantial variation in conceptualizations of radical product innovation, certain insights regarding the features of "radical products" seem to be commonly shared. One such insight that forms the basis for this study is that radical product innovation is multidimensional: two particularly relevant dimensions are the product's technological novelty and its superiority in fulfilling customer needs (Chandy and Tellis 1998). If a product employs a technology that no previous product has employed in a core component, then we label this product "technologically novel." If a product's magnitude of improvement in fulfilling customer needs is substantial compared to other products in the same product category, then we label this product "superior in customer need fulfillment."

Numerous overview studies support the claim that a product's technological novelty and its superiority in meeting customer needs are distinct dimensions. An early exploratory study by Cooper (1979) shows empirically that a new product's superiority in meeting customer needs differs significantly from its technological nature. Garcia and Calantone (2002) point to the importance of distinguishing technological aspects from other marketing-relevant aspects in describing the innovativeness of a new product. Gatignon et al. (2002) state that technological novelty and the impact of new products on customers are distinct from each other. Further, one can find support for this distinction in multiple industries: in the pharmaceutical industry, innovation projects are often evaluated on the basis of their technologically innovative character on the one hand and their potential to address market needs on the other (Loch and Bode-Greuel 2001). In the electronics industry, firms such as Philips shape their technology strategy so that they can cope not only with the rise of novel technologies but also with uncertainty regarding how various technologies will perform in addressing market needs (Lint and Pennings 2001). In the information and communication technology industries as well as semiconductor industries, firms face two distinct challenges, namely, to select feasible, novel technological paths on the one hand and to successfully apply both novel and prior technologies for generating products that deliver superior customer benefits on the other (Iansiti 1998).

Studying how these two dimensions are both interrelated and distinct is relevant for at least two reasons. First, whereas some products qualify as both technologically novel and superior to other products in satisfying customer needs, other products score high on only one dimension. In the photolithographic industry, for example, several of the product innovations that have led to substantial improvement in performance benefits to customers have been based on reconfigurations of established technologies rather than on the discovery of novel technological paths (Henderson and Clark 1990). Examples of products that are technologically novel but fail to provide superior customer-need fulfillment are multiple. In the pharmaceutical industry, several drugs are technologically novel but not superior to alternative drugs in their treatment potential, and several drugs are superior to alternative drugs but not technologically novel.[1]

A second reason for studying these distinct dimensions is that recent research (Sorescu, Chandy, and Prabhu 2003) has shown that innovations that score high along both dimensions are more highly valued by the financial markets than products that score high along only one dimension, underscoring the need for firms to excel at both. Yet, the percentage of such innovations is relatively low. For example, a National Institute for Health Care Management report (2002) notes the low percentage (13%-15%) of FDA-approved drugs

that can be labeled "highly innovative drugs," i.e., medicines that contain new active ingredients and also provide significant clinical improvement.

Despite the importance of these two dimensions, there have been no previous efforts to investigate their distinct drivers. Rather, prior studies have aggregated both dimensions into one radical product-innovation construct (Chandy and Tellis 1998; Sorescu, Chandy, and Prabhu 2003; Wuyts, Dutta, and Stremersch 2004), implicitly suggesting that their drivers are the same. To identify relevant drivers, we combine an organizational learning perspective with recent work on firm boundaries. The first literature stream (e.g., Bettis and Prahalad 1995; Levinthal and March 1993) suggests that developing a unique, internal knowledge base that diverges from existing knowledge and breaks new ground aids in generating product innovations. The second literature stream (e.g., Pisano 1990; Powell, Koput, and Smith-Doerr 1996) suggests that firms should cooperate with other firms and diversify their technological opportunities for generating new products. With few exceptions (e.g., Lee, Lee, and Pennings 2001; Rindfleisch and Moorman 2001), most previous work has focused on either the role of internal knowledge development (e.g., Moorman and Miner 1998) or the role of external knowledge sourcing (Wuyts, Dutta and Stremersch 2004). We consider both and also investigate whether they act as substitutes or complementary paths towards generating technologically novel products and/or products superior in customer-need fulfillment.

In sum, our study contributes to the current new-product development literature in marketing and the innovation literature in at least two ways. First, we investigate what common and distinct factors enable firms to generate technologically novel products and/or products superior in addressing customer needs. Second, we develop a conceptual framework that integrates internal knowledge development and external knowledge sourcing, rather than focusing on one or the other.[2] For an empirical test of our framework, we have used various databases in the pharmaceutical industry. By applying model specifications that allow for identifying both common and distinct drivers, we arrive at findings consistent with our conceptualization of technological novelty and superiority in satisfying customer needs.

In the next section, we discuss the dimensions of technological novelty and superiority in fulfilling customer needs and how internal knowledge development and external knowledge sourcing function as drivers.

Dimensions of Radical Product Innovation

In this section, we first discuss both dimensions of radical products, namely, their technological novelty and superiority in fulfilling customer needs. Then we hypothesize on the likely effects of internal knowledge development and external knowledge sourcing. To conclude the theory section, we consider alternative covariates such as prior experience.

Technological novelty

If a product employs a technology that no previous product has employed in a core component, then we label this product "technologically novel."[3] The generation of technologically novel products requires major dislocation of domain-specific knowledge (Iansiti 1998), due to the major shifts in knowledge bases required to operate the novel core technology (Tushman and Anderson 1986). Hence, such projects require considerable depth in a specified domain of knowledge (Allen, Lee, and Tushman 1980).

Because creating technologically novel products requires firms to select a feasible and effective technical path through careful evaluation and selection of technological opportunities (Fujimoto, Iansiti, and Clark 1996), it involves great uncertainty early in the new product development (NPD) process.[4] More precisely,

can a specific novel technology be usefully applied as a basis for generating new products? Such uncertainty regarding technical applicability typically arises at the beginning stages of the NPD process (see, for example, Bahrami and Evans 1989; Cooper 1993). In the pharmaceutical industry, "phase 1" tests that occur at the beginning of the drug development process are primarily intended to verify that a new compound can be applied to the development of a new drug to ensure that it has no toxic properties and to establish that it has minimum efficiency in fighting a disease (Danzon, Nicholson, and Pereira 2003). At Novartis, using a new technology or mode of action requires a proof of concept in the early stages of the NPD process. Depending on whether minimum levels of efficacy can be demonstrated at this early point in time, a go/no-go decision follows.[5] Clearly, even though early-stage tests imply some minimum expectations regarding performance benefits to customers, whether a new product will eventually *outperform* alternative products is resolved only much later in the process.

Superiority in fulfilling customer needs

If a product's magnitude of improvement in terms of fulfilling customer needs is substantial compared to other products in the same product category, then we label this product "superior in customer-need fulfillment." Achieving superiority in addressing customer needs is challenging and often requires combining diverse knowledge bases and adapting them to ensure a very good match to the requirements of the markets where they will be applied (John, Weiss, and Dutta 1999; Clark and Fujimoto 1991). Prior research has shown that substantial improvements in performance benefits do not always result from novel technologies, but often result from experimentation and reconfiguration of existing technologies (see Henderson and Clark [1990] for examples in the photolithographic alignment equipment industry). In general, firms that build a capability to experiment with and integrate different technologies are more likely to find outstanding product solutions because they can better handle the match with the specific application context (Iansiti 1998). Similarly, in their discussion of the emergence of superior or dominant designs, Tushman and Anderson (1986) stress the importance of experimentation with different technologies. In sum, superior products often result from mixing and matching different, known or novel, technologies.

Pursuing products that are *superior* in customer-need fulfillment to alternative products implies coping with great performance uncertainty: Will the end product outperform the other available products in the same category? Contrary to uncertainty regarding the applicability of a technology in the development of new products, uncertainty regarding the degree of improvement in performance benefits is resolved only towards the end of the NPD process, as only extensive data gathering through prototype testing and eventual test markets will provide the first indications of how well a product performs in satisfying customer needs, as compared to other products in the market (e.g., Wheelwright and Clark 1992).[6] For instance, in the pharmaceutical industry, performance uncertainty in terms of efficacy for patients is reduced only after intensive clinical testing when information becomes available on a drug's therapeutic potential (Danzon, Nicholson, and Pereira 2003; *Economist* 2004). Indeed, as Judy Lewent, CFO at Merck, comments, even though it may be certain at the beginning of a project that a compound has no toxic properties and has minimal effectiveness (and thus can be applied for the development of a new drug), the actual degree of effectiveness as compared to prior drugs in the specific therapeutic category remains uncertain much longer throughout a drug development process (Nichols 1994).

Table 1 summarizes our conceptualization of radical product innovation along both dimensions. Talks with industry experts provided support for this conceptualization. Table 1 also summarizes our conceptualization of internal knowledge development and external knowledge sourcing, to which we turn now.

Table 1

Dimensions of Radical Product Innovation and Role of Internal and External Knowledge

Conceptualization: Dimensions of Radical Product Innovation	**Indicative References**
Technological novelty:	
■ Major dislocation of domain-specific knowledge requires knowledge development in depth	(Iansiti 1998; Tushman and Anderson 1986)
■ High uncertainty regarding technical applicability, particularly early on in the NPD process	(Bahrami and Evans 1989; Cooper 1993)
Superiority in addressing customer needs:	
■ Optimizing match with application context requires experimentation with and integration of diverse knowledge domains	(Clark and Fujimoto 1991; Henderson and Clark 1990; Iansiti 1998)
■ High uncertainty regarding performance benefits, resolved late in the NPD process	(Wheelwright and Clark 1992; Danzon, Nicholson, and Pereira 2003)
Conceptualization: Role of Internal and External Knowledge	**Indicative References**
Development of unique internal knowledge base:	
■ Higher ability to identify novel opportunities because of deviation from prior knowledge	(Levinthal and March 1993; Levitt and March 1988)
■ Higher difficulty to switch to alternative trajectories because of path-dependence and resource commitments	(Christensen 1997; Christensen and Rosenbloom 1995; Coombs and Hull 1998)
Accessing external knowledge through diverse portfolio of R&D agreements:	
■ Higher ability of opportunity identification and experimentation because of broadened technological scope	(Baum, Calabrese and Silverman 2000; Wuyts, Dutta, and Stremersch 2004)
■ Higher flexibility to switch to alternative trajectories because of more diverse set of options	(Hurry 1993; Kogut and Kulatilaka 1994; McGrath 1999)

Internal knowledge development

The organizational learning literature points to the importance of developing a unique, internal knowledge base when pursuing innovative new products (e.g., Bettis and Prahalad 1995; Levinthal and March 1993; Levitt and March 1988). A knowledge base is unique when it is little embedded in prior knowledge, breaks new ground, and extends prior knowledge. Firms have a tendency to adhere to dominant logics and preexisting competences, which inhibits novel learning (Bettis and Prahalad 1995; Levinthal and March 1993; Levitt and March 1988). Firms that manage to build a knowledge base that diverges from existing knowledge and breaks new ground can escape this tendency and enhance the likelihood of successfully generating innovative products. They are more likely to unveil opportunities for new product generation than firms that rely heavily on prior knowledge (Levinthal and March 1993).

However, in knowledge-intensive industries, the development of a unique, internal knowledge base also comes with tradeoffs. It requires knowledge accumulation over time and follows a learning path determined by prior choices and actions (Nelson and Winter 1982; Coombs and Hull 1998). This dependency on earlier choices and actions in knowledge development can lead to inertial trajectories (Christensen and Rosenbloom 1995). In addition to this path-dependency effect, accumulating a unique, internal knowledge base is a resource-intensive process that requires continuous investments and substantial resource allocation over time

(Christensen 1997). In view of these time and resource requirements, firms are limited in the number of unique knowledge trajectories they can reasonably develop (Christensen 1997; Cooper 1993; Iansiti 1998). The drawback is the growth of inflexibility over time, as the path-dependency and heavy resource requirements make it difficult for firms to switch to other technologies if the current technologies do not live up to their promise or if more promising technologies emerge from diverse and distinct knowledge domains (Farrell and Saloner 1985; Levinthal and March 1981).

Let us now turn to the effects of a unique, internal knowledge base along both dimensions of radical product innovation, starting with technological novelty. Recall that technological novelty often results from major dislocation in domain-specific knowledge and in-depth development of rather narrow domains of knowledge (Clark and Fujimoto 1991; Iansiti 1998). A unique knowledge base is more likely to provide opportunities for such major shifts in knowledge domains than a knowledge base that relies heavily on prior knowledge and involves merely incremental advances. Hence, one can expect a positive effect on the generation of technologically novel products. However, a positive effect is less obvious for developing products superior in customer-need fulfillment, as developing such products requires a great deal of flexibility. First, superior products are often created by combining, through experimentation and integration, diverse knowledge domains and adapting them to the requirements of different customer applications (Clark and Fujimoto 1991; Iansiti 1998). Second, generating products superior in customer-need fulfillment implies handling great uncertainty regarding the product's performance benefits, which is reduced only toward completion of the NPD process. As a result of the long time that passes before performance uncertainty is reduced, the drawback of inflexibility caused by path-dependency and resource constraints is particularly severe when firms pursue products that deliver superior customer benefits. This drawback may well neutralize the advantage of identifying new opportunities. Hence,

H1a: The extent to which a firm's internal knowledge base (1) is little embedded in prior knowledge and (2) breaks new ground increases its ability to generate technologically unique products.

H1b: The extent to which a firm's internal knowledge base (1) is little embedded in prior knowledge and (2) breaks new ground is not likely to affect its ability to generate products superior in customer-need fulfillment.

External knowledge sourcing

In knowledge-intensive industries, where technological knowledge changes rapidly and is dispersed among different industry participants, firms have at their disposal an alternative route to accessing knowledge for the generation of new products: engaging in portfolios of R&D agreements with innovative industry partners (Powell, Koput, and Smith-Doerr 1996). Wuyts, Dutta, and Stremersch (2004) describe how established pharmaceutical firms have coped with the rise of innovative biotechnology firms by developing portfolios of R&D agreements with these innovative firms in order to gain access to vital new domains of knowledge. Similar strategies were employed by telecommunication carriers and IT manufacturers in the eighties and early nineties. In contrast to the lengthy and path-dependent trajectory of developing unique knowledge internally, R&D agreements with other firms can be signed at any stage of the NPD process, which can substantially reduce the time to product launch. Previous research has singled out the technological diversity of a firm's portfolio of R&D agreements as an important determinant of a firm's ability to innovate (Wuyts, Dutta, and Stremersch 2004).

In line with recent conceptualizations on the relevance of agreement portfolios (Gulati, Nohria, and Zaheer 2000), we argue that (1) a

diverse portfolio of R&D agreements broadens a firm's technological scope by providing direct access to external resources, and (2) the diversity of the portfolio is also a resource in its own right because it enhances the firm's flexibility. For the first argument, we refer to prior literature on the boundaries of the firm that has illustrated how a diverse portfolio of R&D agreements broadens a firm's technological scope by giving the firm the opportunity to engage in many more technological areas than when it goes it alone (e.g., Baum, Calabrese, and Silverman 2000; Wuyts, Dutta, and Stremersch 2004).

Our second argument—that the diversity of a portfolio of R&D agreements offers the firm flexibility in pursuing and abandoning technological options—has not received attention in prior marketing literature. For this argument, we refer to the "real-options" perspective (Kogut and Kulatilaka 1994; McGrath 1999; McGrath and Nerkar 2003). An investment in a "real option" (a particular domain of knowledge) conveys the right, but not the obligation, to a firm to make further investments or defer such investments in the future (McGrath and Nerkar 2003). Real-option reasoning can be applied in contexts characterized by uncertainty regarding the link between investments and outcomes (Chatterjee, Lubatkin, and Schulze 1999) and by time dependence of future events on current decisions and a possibility to exercise options (Kogut and Kulatilaka 1994). Recently, it has been applied to the study of joint ventures (Kogut 1991) and alliances (Hurry 1993). An important insight from real-options reasoning is that real options (or R&D agreements, for that matter) should be considered jointly as a portfolio rather than in isolation (McGrath 1999). Diverse portfolios of R&D agreements allow firms to take stakes in diverse technological domains while giving them the option at different times to either further invest or divest, as uncertainty diminishes.[7] In other words, the diversity of a firm's portfolio of R&D agreements enables the firm to circumvent the path-dependency problem and to cope with uncertainty that lasts over time.

Let us now turn to the likely effect of a diverse portfolio of R&D agreements on both dimensions of technological novelty and superior customer-need fulfillment. A broadened technological scope through access to diverse external resources is likely to aid in the development of technologically novel products. By developing technologically diverse portfolios of R&D agreements, firms can cope with the pace of the industry's technological evolution, identify unique technological opportunities, and selectively apply new technologies in the development of new products. A broadened technological scope is also beneficial for developing products that offer significant, enhanced customer benefits, as it allows firms to better compare and evaluate alternative opportunities and offers more possibilities for experimentation and for integrating different technologies.

More importantly, the benefit of flexibility as described in the real-options argument is particularly relevant for developing products that significantly outperform other products in satisfying customer needs. Through a diverse portfolio of R&D agreements, firms can have a stake in alternative trajectories and further invest or divest in alternative trajectories as performance uncertainty diminishes. One illustration of the relevance of this real-options argument in generating superior drugs is Novartis, which provides initial funding to a number of innovative biotechnology firms. At later stages in the NPD process, it allocates additional funding only to those projects with greatest potential as uncertainty regarding the drug's efficacy is reduced (see activity reports of the Novartis Venture Fund). As reported by Dr. Daniel Vasella, president and CEO at Novartis, the ultimate goal of managing such a portfolio is to successfully fulfill patients' unmet needs. In sum,

H2a: The extent to which a firm's portfolio of R&D agreements is technologically diverse increases its ability to generate technologically novel products.

H2b: The extent to which a firm's portfolio of R&D agreements is technologically diverse increases its ability to generate products superior in customer-need fulfillment.

Complementarity of unique internal knowledge base and diverse R&D agreement portfolio

Do a unique, internal knowledge base and a diverse portfolio of R&D agreements complement each other in the generation of innovative products, or are they distinct paths to innovative products? This question is crucial for managers who wish to optimize their NPD outcomes, but little research is available to answer it (for one of the first attempts to address this issue, see Lee, Lee, and Pennings [2001]). We elaborate on the real-options argument described above. By carefully investing in successful R&D agreements (i.e., exercising selected real options) and divesting in less successful ones (i.e., abandoning other real options) as uncertainty lessens over time, firms can selectively assimilate external knowledge to give direction to the development of a unique, internal knowledge base. In that way, firms can use networks to select more rewarding opportunities that match and enhance their internal knowledge base (Lee, Lee, and Pennings 2001). Hence, real-options reasoning suggests a complementarity effect. Yet, one should not overlook an inherent complexity: in a complicated, fast-paced environment, combining appropriate technology and know-how from different domains remains difficult. Even firms that have a novel, internal knowledge base may fail to assimilate knowledge from outside because of the unique routines and processes that underlie their internal knowledge base and that require a unique mindset not necessarily compatible with external knowledge. If internal knowledge and external knowledge require such distinct mindsets, processes, and routines, there may be little room for them to play a complementary role. The latter argument suggests there is no complementarity effect.

Are there differences in the complementarity or noncomplementarity of these two drivers along the two dimensions of radical product innovation? The generation of technologically novel products often entails major dislocation in domain-specific knowledge (Tushman and Anderson 1986; Henderson and Clark 1990). A unique, internal knowledge base developed to generate technologically novel products may therefore aggravate the difficulty of blending internal knowledge with externally sourced knowledge. In other words, the drawback of incompatibility is particularly severe in the pursuit of products that are technologically novel. The real-options argument in favor of complementarity is particularly valid for the pursuit of products superior in customer-need fulfillment. Developing products superior in customer-need fulfillment entails high performance uncertainty that tends to last until very late in the NPD process. The time that elapses before performance uncertainty is reduced is substantial and can cause inflexibility if the firm has to rely only on its own internal technological knowledge, due to path-dependency effects and resource constraints. A diverse portfolio of agreements, as a portfolio of real options on alternative technologies, provides a firm with increasing information over time regarding the relative potential of alternative knowledge trajectories. Also, it provides firms with a stake in these alternative knowledge trajectories, which facilitates switching trajectories if required. As such, a diverse portfolio can be used to give direction to a firm's internal knowledge base and alleviates the risk of lock-in with a trajectory that won't deliver superior customer benefits.

Because the argument in favor of complementarity suggested by real-options reasoning is particularly relevant to superiority in customer-need fulfillment, while the counter-argument of incompatibility is particularly relevant to technological novelty, we expect:

H3a: The joint occurrence of a unique, internal knowledge base with a diverse portfolio of R&D agreements has a negative effect on a firm's ability to generate technologically novel products.

H3b: The joint occurrence of a unique, internal knowledge base with a diverse portfolio of R&D agreements has a positive effect on a firm's ability to generate products superior in customer-need fulfillment.

Other covariates

Here, we consider experience effects, both within and across dimensions, to better capture the interdependency of both dimensions. We also list a number of variables to control for in any innovation model.

Experience Effects. We first consider if there are any experience effects within each dimension. While one may intuitively expect that experience with generating technologically novel (superior) products aids in the generation of a new, technologically novel (superior) product, such experience effects are far from straightforward. Recent literature on firm incumbency and cannibalization (see Chandy and Tellis 1998, 2000) suggests that it is difficult for firms to develop multiple, radical innovations over time. Further, as a specific challenge for regularly developing technologically novel products, the organizational learning literature discusses the danger of lock-in with preexisting competences and dominant designs (Bettis and Prahalad 1995; Levinthal and March 1993; Levitt and March 1988). We will test to see if firms experienced with generating innovations have an edge over less experienced firms in developing new innovations.

Second, we consider if there are any cross-experience effects. Does experience with generating superior products facilitate the subsequent generation of technologically novel products? And does experience with generating technologically novel products facilitate the subsequent generation of superior products? There are arguments in favor of such cross-effects. On the one hand, experience with generating superior products may facilitate the subsequent generation of technologically novel products. Market and customer information can enhance technological innovation in turbulent industries (Han, Kim, and Srivastava 1998): firms that have developed many superior products in the past have better insight into the exact needs of customers, which may enhance their ability to identify new technological opportunities to satisfy those needs. On the other hand, experience with generating technologically novel products may facilitate the subsequent generation of superior products. Firms that have developed many products based on novel technologies in the past are at the front line of technological progress and benefit from a wide cognitive scope. Their experience with new technologies may lead to opportunities for knowledge spillovers to different application contexts (Henderson and Cockburn 1996). This may give them a better point of departure for matching technologies with new application areas with maximum payoff in terms of customer benefits (Iansiti 1998).

An argument against the occurrence of such cross-effects, however, is that strong experience along one product-innovation dimension may have implications regarding internal NPD processes that are not necessarily compatible with product innovation along the other dimension. This may be particularly relevant for the influence of experience with technologically novel products on the generation of products superior in customer-need fulfillment, because firms that continuously develop novel products by causing knowledge dislocation and in-depth development of narrow knowledge domains may have difficulties with the flexibility and variety of knowledge required for generating superior products. Which of these arguments prevails is an empirical question.

Additional Control Variables. We include a number of additional control variables that may influence firms' ability to generate technologically novel and/or superior products. First, we account for the (quality-corrected) scope of a firm's internal knowledge base. Second, we control for the size of the firm's portfolio of R&D agreements. Third, we control for firm size and R&D expenditures. Finally, we include year-

dummy variables and a trend variable to control for time shocks and general industry patterns.

Empirical Test

We study the pharmaceutical industry, one of the most important industries in the modern economy, with annual sales of around $400 billion (*Economist* 2004). This industry is particularly interesting for a number of reasons. First, it is a prototype example of a knowledge-intensive industry in which radical innovation occupies a central position. Second, the relevance of distinguishing between the two dimensions of new product innovation is apparent from the many products that fall in either one of the two off-diagonal classes (that is, they excel at one of the two dimensions). For example, many drugs are based on new technologies but deliver therapeutic efficacy comparable to previous products. Third, since the biotechnology revolution in the eighties, pharmaceutical firms rely as much on external knowledge search as on internal knowledge development (Pisano 1990; Powell, Koput, and Smith-Doerr 1996), which poses specific challenges for generating radical innovation. Firms such as Eli Lilly and GlaxoSmithKline consider partnerships with external partners indispensable and complementary to the development of their internal capabilities. Industry experts have also pointed to the applicability of real-options reasoning in the context of biotechnology, a perspective actively employed by industry proponents such as Merck (Remer, Ang, and Baden-Fuller 2001). And, finally, a variety of data sources are available that can be integrated to study this phenomenon. Our findings will be of direct relevance to related industries that have undergone the biotechnology revolution: chemicals, agriculture, food processing, environmental mining, energy, cosmetics, and IT (Enriquez and Goldberg 2000). More generally, our findings may be translated to turbulent industries where knowledge evolves quickly and is dispersed among large numbers of industry participants and domains of technological know-how.

Data sources

We have combined four data sources: Recap, FDA Drug Approvals, USPTO/NBER, and COMPUSTAT.

Recap (Recombinant Capital) contains information on R&D agreements between pharmaceutical firms and biotechnology firms. For each agreement, it also provides information on the underlying technology (categorized by biotech experts). This information enables us to calculate the technological diversity of each pharmaceutical firm's portfolio of agreements during 1985-1999.

The FDA drug approval list provides data on newly approved drugs, including information on their technological novelty and therapeutic potential (from 1991 on).

The USPTO and NBER patent databases contain useful information that can qualify a firm's internal knowledge base. In the NPD process, patent data are the "earliest" available records of internal knowledge available for research. Not all patents translate into new products: patent data represent large portions of both failed and successful inventions (Fleming 2001). The USPTO database contains the original patents; the NBER database contains descriptors of each individual patent, such as the number of claims and patents cited.

COMPUSTAT provides information on each firm's size and R&D expenses.

In all, we collected data for 52 firms within the period 1991-1999 (on average, 8 years per firm), covering about 700 R&D agreements and 273 drugs, 105 of which score high on at least one dimension of radical product innovation.

Measures

Dependent Variables[8]. Superior customer-need fulfillment is measured by a binary variable, $CUSTNEED_{it}$, obtained from the FDA drug approval lists. The FDA distinguishes between standard drugs and drugs with high therapeutic

Table 2
Frequencies of Two Dimensions for Approved Drugs
[Number of drugs (%)]

	High Therapeutic Potential	Standard Therapeutic Potential	Totals
Chemical type 1 (new molecular entity)	35 (13%)	54 (20%)	89 (33%)
Other chemical types	16 (6%)	168 (61%)	184 (67%)
Totals	51 (19%)	222 (81%)	273 (100%)

potential. More specifically, standard drugs have "therapeutic qualities similar to those of an already marketed drug." High treatment-potential drugs represent "an advance over available therapy of drugs." The label high treatment potential is therefore a good indication of the relative superiority of this drug as compared to prior drugs in curing the corresponding disease (i.e., in fulfilling customer needs in the pharmaceutical industry). $CUSTNEED_{it}$ = 1 if firm *i* generated an innovation that provides superior customer-need fulfillment (i.e., received FDA approval for a drug with high therapeutic potential) in year *t*.

Technological novelty ($TECHINNOV_{it}$) is measured by another binary variable that is also provided by the FDA. More precisely, the FDA assigns a chemical type 1 to all drugs that are based on an active ingredient that has never been marketed before (also referred to as new molecular entities). Other chemical types the FDA assigns include chemical type 2 (a chemical derived from an active ingredient already marketed) and chemical type 3 (a new dosage form or new formulation of an active ingredient already on the market). The label chemical type 1 is thus a good indication for the technological novelty of the new drug. Hence, $TECHINNOV_{it}$ = 1 if firm *i* generated a technological innovation (i.e., received FDA approval for a new molecular entity) in year *t*.

In the period 1992-1999, 13% of the drugs approved by the FDA for our sample firms score 1 on both binary variables, i.e., they both have high therapeutic potential and contain a unique active ingredient (hence, they are "radical innovations" according to Chandy and Tellis's 1998 definition). This percentage is in line with recent industry and cross-industry estimates (Wind and Mahajan 1997). However, when also incorporating off-diagonal cells, 39% of all drugs approved turn out to have high therapeutic potential and/or contain a unique active ingredient. In sum, there are twice as many drugs that score high on only one of the two dimensions of radical product innovation as there are drugs that score high on both, which provides additional empirical justification for studying the distinct drivers of both dimensions. Table 2 provides frequencies along both dimensions for our database.

As an example, Lipitor, developed by Parke-Davis Research and approved by the FDA in 1996 for the treatment of cholesterol, has been assigned chemical type 1 and is labeled a drug with high therapeutic potential. Lipitor, the world's largest-selling pharmaceutical, is based on a unique active ingredient or mode of action, *atorvastatin calcium*, and is the only drug in its class that lowers both elevated LDL ("bad") cholesterol and triglycerides (a fatty substance in the bloodstream) in patients with elevated cholesterol, making it an excellent therapy as an adjunct to diet for a broad range of patients.[9]

Independent Variables. We include as independent variables a series of firm descriptors (unit of measurement is firm *i* at time *t*). First, we measure reliance on existing knowledge $(RELPRIOR_{it})$ as the average number of patents cited in firm *i*'s patents. The more a patent relies on previous knowledge, the more this patent should cite other patents, as a legal way of delimiting the property rights awarded to that patent. In other words, the number of patents cited is an objective and accurate indicator of the extent to which the patent relies on existing knowledge, i.e., "uses existing ideas" (Caballero and Jaffe 1993) or relies on "prior art" (Mowery, Sampat, and Ziedonis 2002). Prior research has

consistently found that patents in more traditional technological domains tend to cite a higher number of other patents, whereas patents in novel technological domains cite fewer patents and are hence more "original" (Hall, Jaffe, and Trajtenberg 2001).

Second, we measure the extent of breaking new ground ($BREAK_{it}$) as the average number of claims per patent for firm i. The more novel a patent, the more the firm can claim on the basis of that patent; hence, the number of claims per patent is indicative of the scope of an invention (Hall, Jaffe, and Trajtenberg 2001). As claims describe exactly what the patented invention does that has never been done before (Hall, Jaffe, and Trajtenberg 2001) and the number of claims hence reflect the scope of impact (Lanjouw and Schankerman 1999; McGrath and Nerkar 2003), the average number of claims per patent for firm i is an indication of the overall novelty of its internal knowledge base. With regard to both patent measures, it is important to note that while the patentee obviously has the incentive to cite as few other patents as possible and to claim as much as possible in a patent application, it is the patent examiner who verifies the correctness of patents cited and claims and eventually demands that other patents are cited or that the claims be narrowed before granting (Lanjouw and Schankerman 1999). This important role of the patent examiner enhances the validity of these measures.

Industry reports and our own interviews with practitioners in the pharmaceutical industry reveal that it takes 10 years on average for patents to turn eventually into approved drugs (e.g., Nichols 1994). Accounting for some variation, we consider the patents in the time window ($t-12$, $t-8$) to influence drug generation at time t. While we used this window for our estimations, we also tried a number of alternative windows by changing the lags within realistic boundaries (for example, [$t-15$, $t-10$]). Our findings are robust for the exact choice of time frame. Therefore, we report the results for the time frame ($t-12$, $t-8$), which corresponds best with what is observed in the pharmaceutical industry (Nichols 1994).

Diversity of external knowledge sourcing ($TECHDIV_{it}$) is approximated by the technological diversity of firm i's portfolio of R&D agreements with biotechnology firms that has been built up at time t. The Recap database contains a classification of technologies into 42 classes. Consistent with prior literature (Powell, Koput, and Smith-Doerr 1996), the diversity index equals one minus the sum of squared proportions of each technology's occurrence in a firm's portfolio. R&D agreements can differ substantially with respect to the stage in the development process at which they are signed, from early in the development process to the late stage of clinical trials. To make sure that we incorporate all potentially relevant agreements that can affect the generation of new products at time t, we therefore consider the firm's entire agreement portfolio (starting in 1985, the inception of alliance activity in the industry) up to year $t-1$ (this operationalization and lag specification are identical to Wuyts, Dutta, and Stremersch [2004]). In order to verify the sensitivity of our results to the choice of time lag, we also specified alternative time lags within realistic boundaries (two and three years) and found our results again to be very robust.

Experience with generating technologically novel drugs ($EXPNOV_{it}$) and drugs with superior efficacy ($EXPSUP_{it}$) was measured as the cumulative number of technologically novel drugs (i.e., drugs with chemical type 1) and superior drugs (i.e., drugs with high therapeutic potential), respectively. We lagged both experience variables with one period.

Control Variables. (1) The scope of a firm's internal knowledge base is measured as the count of its citation-weighted patents, again observed in the period ($t-12$, $t-8$); (2) the size of a firm's portfolio of R&D agreements is measured by counting the total number of its R&D agreements from 1985 until $t-1$; (3) firm

Table 3
Correlation Matrix of Variables

	RELPRIOR	***BREAK***	***TECHDIV***	***EXPNOV***	***EXPSUP***	***SIZEKNO***	***SIZEPOR***	***SIZE***	***R&D***
Reliance on existing knowledge *(RELPRIOR)*	1								
Breaking new ground *(BREAK)*	.56	1							
Diversity of portfolio *(TECHDIV)*	.06	.26	1						
Experience effect of technological novelty *(EXPNOV)*	−.06	.13	.47	1					
Experience effect of superiority *(EXPSUP)*	−.03	.08	.37	.79	1				
Size of knowledge base *(SIZEKNO)*	.16	.22	.43	.36	.34	1			
Portfolio size *(SIZEPOR)*	−.00	.18	.64	.74	.56	.47	1		
Firm size *(SIZE)*	.04	.29	.44	.38	.29	.44	.49	1	
R&D expenditures *(R&D)*	−.12	.07	.46	.50	.47	.51	.62	.64	1

size is measured as the log of the number of employees as reported in COMPUSTAT; (4) R&D expenditures are derived from COMPUSTAT. Both firm size and R&D expenditures are lagged with one period. Finally, we also specified a time trend and year-dummy variables (one of which, 1996, was significant and therefore retained in the final model)[10]. Table 3 contains a correlation matrix of the variables.

Model

We specify a random-effects bivariate probit model, which allows for the simultaneous estimation of the effects of explanatory variables on both radicality dimensions (which are operationalized as binary response variables). A bivariate probit model is particularly suited for answering our research question, because the disturbances of the two equations (generation of a product that is technologically novel; generation of a product that outperforms other products in terms of satisfying customer needs) are likely to be correlated: even though we capture internal knowledge development, external knowledge sourcing, and a number of other covariates, our list of variables is unlikely to be exhaustive. We cannot exclude that other firm descriptors influence both dependent variables and should therefore allow the error terms to be freely correlated. Estimating the two equations separately would lead to consistent but inefficient parameter estimates.

In view of the panel data structure of our dataset (432 observations over 52 firms), and realizing that we cannot capture all firm characteristics that may have a bearing on radical innovation, we estimate a random-effects bivariate probit model. We also specified alternative models in which we randomized the parameters for subsequent sets of covariates through a series of random-parameter bivariate probit models, but these random parameter models did not lead to any significant improvements in fit nor did they change the signs and significances of the parameters, which enhances

our confidence that the random-effects specification in combination with the large number of firm-specific control variables lead to a fairly homogeneous sample. The model is estimated with full-information maximum likelihood, and the disturbances are allowed to be freely correlated. More specifically, the model is as follows:

$$\begin{aligned} TECHINNOV^{*}_{it} &= \beta_{1,1} RELPRIOR_{it-8} \\ &+ \beta_{2,1} BREAK_{it-8} + \beta_{3,1} TECHDIV_{it-1} \\ &+ \beta_{4,1} RELPRIOR_{it-8} {}^{*} TECHDIV_{it-1} \\ &+ \beta_{5,1} BREAK_{it-8} {}^{*} TECHDIV_{it-1} \\ &+ \beta_{6,1} EXPNOV_{it-1} + \beta_{7,1} EXPSUP_{it-1} \\ &+ \beta_{k,1} CONTROLS_{it-1} + \varepsilon_{it1} + u_{i1} \end{aligned} \quad (1)$$

and $TECHINNOV_{it} = 1$ if $TECHINNOV^{*}_{it} > 0$; $TECHINNOV_{it} = 0$ otherwise.

$$\begin{aligned} CUSTNEED^{*}_{it} &= \beta_{1,2} RELPRIOR_{it-8} \\ &+ \beta_{2,2} BREAK_{it-8} + \beta_{3,2} TECHDIV_{it-1} \\ &+ \beta_{4,2} RELPRIOR_{it-8} {}^{*} TECHDIV_{it-1} \\ &+ \beta_{5,2} BREAK_{it-8} {}^{*} TECHDIV_{it-1} \\ &+ \beta_{6,2} EXPNOV_{it-1} + \beta_{7,2} EXPSUP_{it-1} \\ &+ \beta_{k,2} CONTROLS_{it-1} + \varepsilon_{it2} + u_{i2} \end{aligned} \quad (2)$$

and $CUSTNEED_{it} = 1$ if $CUSTNEED^{*}_{it} > 0$; $CUSTNEED_{it} = 0$ otherwise.

$$\begin{aligned} &\text{With } [\varepsilon_{it1}, \varepsilon_{it2}] \sim \text{bivariate normal (BVN)} \\ &[0,0,1,1,\rho], -1 < \rho < 1, \\ &[u_{it1}, u_{it2}] \sim \text{bivariate normal (BVN)} \\ &[0,0,1,1,\theta], -1 < \theta < 1 \end{aligned} \quad (3)$$

Results and Discussion

The results of the random-effects bivariate probit model appear in Table 4. We first tested to see if the bivariate probit model leads to a significant improvement in fit when compared to estimating two separate probit models. As separate binary probit models are nested in the bivariate probit model, we used a simple likelihood-ratio test. (For the separate probit models, the joint likelihood is the product of the two separate marginal likelihoods.) This test indicates that the superiority of a bivariate model specification over separate probit model specifications is significant at 1%. Similarly, we find that the error terms are significantly correlated at 1%. As reported earlier, the findings are robust for alternative lag specifications. Also, the results are robust when we only consider the dataset for those firm/year combinations that correspond with at least one product approved by the FDA (either radical or incremental). This is an indication that the zeros in our dataset (that correspond with either no products approved or only incremental products approved) do not bias the results. We also tested for potential multicollinearity and found all variance inflation factors to be well within acceptable limits, with a maximum value of 4.30 and a mean of 2.21.

Overview findings

Direct Effect of Developing a Unique, Internal Knowledge Base. We find evidence for the positive effect of a unique, internal knowledge base on the generation of technologically novel products. Both the negative effect of reliance on prior knowledge[11] ($\beta = -.051$; $p < .05$) and the (weakly) positive effect of the degree of breaking new ground ($\beta = .018$; $p = .10$) support H1a. We find quite a different picture for the other dimension. In fact, we do not find evidence of a direct effect of the development of a unique, internal knowledge base on the generation of products that are superior in terms of fulfilling customer needs, either for reliance on prior knowledge ($\beta = -.049$; $p = .20$) or for breaking new ground ($\beta = .019$; $p = .28$), as expected (H1b). We will cover this and other findings in the discussion section and now proceed with an overview of other findings.

Direct Effect of Developing a Diverse Portfolio of R&D Agreements. We find support for the positive effect (H2a) of technological diversity of a firm's portfolio of R&D agreements on the generation of technologically novel products ($\beta = .515$; $p < .01$). Similarly, we find a positive effect of portfolio diversity on the generation of products that are superior in terms of fulfilling customer needs ($\beta = .581$; $p = .069$), in support of H2b.

Table 4

Estimated Results of Random-Effects Bivariate Probit Model

	Coefficient (standard error) Technological Novelty	Superiority
Constant (randomized)	Mean: −1.396 *** (Scale: .111)	Mean: −1.518 ** (Scale: .067)
Reliance on prior knowledge *(RELPRIOR)*	−.051 (.025) **	−.049 (.038)
Breaking new ground *(BREAK)*	.018 (.010) *	.019 (.017)
Diversity of portfolio *(TECHDIV)*	.515 (.199) ***	.581 (.321) *
*RELPRIOR*TECHDIV*	−.033 (.067)	−.244 (.101) ***
*BREAK*TECHDIV*	−.003 (.040)	.118 (.058) **
Experience effect of technological novelty *(EXPNOV)*	−.006 (.063)	−.044 (.061)
Experience effect of superiority *(EXPSUP)*	.262 (.094) ***	.306 (.083) ***
Control variables:		
Scope internal knowledge base	−.000 (.001)	.000 (.000) **
Portfolio size	.008 (.008)	−.002 (.009)
Firm size	.542 (.169) ***	.098 (.210)
R&D	.118 (.108)	.254 (.109) **
Trend	−.049 (.038)	−.053 (.039)
Year dummy 1996	.472 (.167) ***	.585 (.184) **

* $p<.10$, ** $p<.05$, *** $p<.01$

Complementarity of Internal Knowledge Development and External Knowledge Sourcing. We do not find evidence that the joint occurrence of a unique knowledge base and a diverse agreement portfolio suppresses the generation of technologically novel products (contrary to H3a), with insignificant parameters for the interactions of portfolio diversity with both reliance on prior knowledge ($\beta = -.033$; $p = .62$) and breaking new ground ($\beta = -.003$; $p = .94$). In contrast, we find support for the complementarity of internal knowledge development and external knowledge sourcing in the generation of superior products (in support of H3b), with a negative interaction between portfolio diversity and reliance on prior knowledge ($\beta = -.244$; $p < .01$) and a positive interaction between portfolio diversity and breaking new ground ($\beta = .118$; $p < .05$).

Experience Effects and Cross-over Effects. Our findings with respect to experience effects are rather surprising. We find only a direct experience effect along the dimension of superiority in fulfilling customer needs ($\beta = .306$; $p < .01$). Experience with technologically novel products in the past does not seem to affect the generation of new, technologically novel products ($\beta = -.006$; $p = .929$). As to the cross-experience effects, we find that prior experience with products superior in customer-need fulfillment increases the likelihood of generating technologically novel products ($\beta = .262$; $p < .01$). However, prior experience with generating technologically novel products does not influence the likelihood of generating new products superior in customer need fulfillment ($\beta = -.044$; $p = .476$).

Control Variables. As we will discuss below, some of our findings with respect to the control variables are also worth discussing, more precisely, the significant, positive effect of firm size on technological novelty ($\beta = .542$; $p < .01$) and the significant positive effect of scope of internal knowledge base on superiority ($\beta = .0002$; $p < .01$).

Discussion

Overall, we find support for the argument that different dimensions of radical product innovation have different drivers. This study's findings are relevant to managers in the pharmaceutical industry and related industries, as they provide insight into (1) the differences between technological novelty and superiority in fulfilling customer needs as distinct dimensions of radical product innovation and (2) the payoff of investing in internal knowledge development and external knowledge sourcing, evaluated along both dimensions. Next we summarize our most important findings.

1. A unique, internal knowledge base and a diverse portfolio of agreements seem to be direct and distinct paths to the generation of technologically novel products. The significant direct effects of internal knowledge development and external knowledge sourcing seem to indicate that they are alternative routes towards the development of technologically novel products. This provides support for the arguments in the literature on organizational learning and organizational boundaries, respectively, that building a unique knowledge base and broadening one's technological scope through R&D agreements aid in identifying novel opportunities. We find no evidence that they reinforce one another, which suggests that they are independent routes rather than mutually reinforcing routes in the pursuit of technologically novel products. This finding is consistent with our conceptualization that pursuing technological novelty entails major dislocation in knowledge development compared to pursuing products based on existing technologies, which reduces the likely complementarity with externally sourced knowledge. Also, the lack of a significant complementarity effect suggests that the flexibility advantage of a diverse portfolio of agreements, as real options, is less relevant for the development of technologically novel products. This may be due to the fact that generating such products entails uncertainty regarding the applicability of novel technologies at the beginning rather than at the end of the NPD process.

2. A diverse portfolio of agreements has a direct positive impact on the generation of products superior in customer-need fulfillment, whereas a unique knowledge base has no direct effect. Contrary to the development of technologically novel products, the development of a unique, internal knowledge base and the development of a diverse portfolio of R&D agreements do not seem to be independent alternative routes to superior products. As for the effect of a diverse portfolio of R&D agreements, we find that it aids directly along the superiority dimension, consistent with the observation that generating superior products involves coping with higher performance uncertainty. A sole focus on a unique, internal knowledge base does not aid in generating products that are superior to other products in fulfilling customer needs. As we argued before, the risk for lock-in is particularly severe for the development of superior products given the long time it takes for performance uncertainty to dissolve and the scarcity of firms' internal resources that can be allocated across different trajectories.

3. A unique, internal knowledge base aids in generating products superior in customer-need fulfillment when complemented with a diverse portfolio of agreements. The combination of a lack of a complementarity effect in the technological novelty equation and the presence of a complementarity effect in the superiority equation is again consistent with the analogy of the portfolio of R&D agreements as a portfolio of real options. We suggested that a diverse portfolio reduces a firm's inflexibility and gives informed direction to the development of the internal knowledge base. As discussed before, the need

for flexibility is particularly severe in the pursuit of superior products. The combination of a lack of a direct effect of a unique, internal knowledge base and the presence of a complementarity effect with external knowledge on generating products superior in customer-need fulfillment provides some empirical support to the claim that firms cannot go it alone in knowledge-intensive industries (Pisano 1990). Interestingly, the finding that the often-debated control variable—firm size—has a positive effect only on the generation of technological novelty and not on the generation of superior products is in line with this interpretation. Indeed, it has been argued in prior literature that as firms grow larger, their flexibility gradually diminishes (Hannan and Freeman 1984). Again, consistent with the other findings, we find that the *scope* of a firm's internal knowledge base significantly enhances the firm's ability to generate superior products.

Note that the findings in 1 through 3 combined have particular managerial relevance for two reasons. First, the findings relate the challenge of generating technologically novel products and superior products directly to the managerial problem of balancing internal knowledge development and external knowledge sourcing. Whether or not the latter two are complementary is not straightforward, but is contingent upon the specific dimension of radical product innovation considered. Second, the findings seem to justify the recent trend in technology-intensive industries to employ real-options reasoning when selecting and evaluating R&D agreements. Real-options reasoning sheds new light on partner-selection behavior in environments characterized by high uncertainty that lasts throughout the product development process. The importance of real-options reasoning in the pharmaceutical industry is underscored by the observation that several pharmaceutical firms (e.g., Novartis) initially invest in many, diverse agreements and later on, as uncertainty regarding therapeutic potential diminishes, make their final decisions regarding each agreement to either further invest or divest.

4. Experience with developing products superior in customer-need fulfillment aids in the subsequent generation of both superior and technologically novel products. Experience with developing technologically novel products, however, does not affect the likelihood of generating products along either of the two dimensions. On the one hand, the effect of experience with products superior in customer-need fulfillment on the subsequent generation of technologically novel products is consistent with the argument that firms derive input for new technologies from their deep insights into customer needs (Han, Kim, and Srivastava 1998). On the other hand, the lack of experience effects with regard to technological novelty illustrates the inherent difficulty firms have in generating a series of subsequent technological innovations, consistent with the argument of potential lock-in with preexisting competences (Bettis and Prahalad 1995; Levinthal and March 1993; Levitt and March 1988) as well as firm-incumbency arguments (see Chandy and Tellis 2000).

As interesting as our finding that innovations superior in customer benefits trigger technological innovations is the finding that the reverse does not hold. This finding rejects the suggestion that firms at the forefront of technological progress can effectively identify new application areas where these technologies can be applied for superior customer benefits (Iansiti 1998). The insignificant effect is in line, however, with textbook examples of firms renowned for their technological creativity but notorious for their inability to turn technological innovations into commercial successes. Consistent with our theorizing, we suggest that this may be due to, among other reasons, failure to achieve the flexibility and variety of knowledge required for coping with uncertainty regarding customer-need fulfillment.

In all, the findings related to experience underscore the importance of pursuing products superior in customer-need fulfillment, not only because of the direct benefits of better satisfying customer needs but also because the generation

of such products is a possible source of inspiration for developing novel technologies to match customer needs. Our database, however, does not contain direct measures of these internal processes. This limitation offers an opportunity for future research. Below, we reflect on other limitations and opportunities for future research.

Conclusion

Our study was a first attempt to contrast the important dimensions, and their drivers, of radical product innovation. Our findings show that technological novelty and superiority in fulfilling customer needs have both mutual and distinct drivers. The development of a unique, internal knowledge base and the development of a diverse portfolio of R&D agreements play important roles in the generation of technologically novel as well as superior products, albeit in different ways. We find evidence of the complementarity of a unique, internal knowledge base and a diverse portfolio of agreements in the pursuit of products superior in customer-need fulfillment, which is consistent with the analogy of an R&D agreement portfolio as one of real options. We do not find any complementarity effect in the pursuit of technologically novel products, however, which is consistent with industry observations that technological novelty requires major dislocation in domain-specific knowledge.

Further, we find that the development of a unique, internal knowledge base has a direct positive effect on a firm's ability to generate technologically novel products, but it seems to be insufficient for generating products superior in customer-need fulfillment. For the latter, a diverse portfolio of agreements is required, which, we suggest, can give direction to the firm's internal knowledge base. This finding is in line with industry reports (e.g., the Novartis Venture Fund reports) that indicate that pharmaceutical firms continue to engage in many, diverse R&D agreements with better satisfying customer needs as an ultimate objective. It is noteworthy that building experience in generating products superior in customer-need fulfillment aids in the subsequent generation of not only superior products but also technologically novel products. Experience with technologically novel products does not seem to affect future product innovation.

In all, these findings are in line with our proposed conceptualization of both dimensions of radical product innovation. This conceptualization and the consistent pattern of findings may be useful for managers who pursue radical product innovation in technology-intensive industries. The popular notion that firms in such industries "cannot go it alone" (Baum, Calabrese, and Silverman 2000; Pisano 1990) is supported by our findings, particularly with regard to the dimension of superiority in satisfying customer needs. Further, industry experts report many new products falling in off-diagonal cells in combination with a downward trend in the generation of truly innovative products that score high along both dimensions (National Institute for Health Care Management 2002). Hence, our findings are relevant for practice in that they provide first insights into how individual firms can generate products that are both technologically novel and superior in customer-need fulfillment.

Our primary objectives in the study were to provide empirical support for the fact that technological novelty and superior need fulfillment are distinct dimensions of product radicality, and for the argument that both internal knowledge development and external knowledge sourcing are relevant in the pursuit of new products along both radicality dimensions. Clearly, more research is warranted to explore further the distinction between both radicality dimensions. For example, there is a clear need for further investigation of the different sources of uncertainty, namely, uncertainty regarding the applicability of novel technologies versus uncertainty regarding performance benefits. While we were guided in our conceptualization by industry literature and our talks with practi-

tioners, providing some face validity to our theorizing and interpretation of results, future research is required to uncover firms' internal processes that we were unable to describe. A useful complement to this study would be a case-based account of NPD activities in large firms with specific attention to the sources of uncertainty, the integration of technologies, and the impact of dislocation in domain-specific knowledge.

Our empirical test is restricted to the pharmaceutical industry, which is no doubt an industry with particular characteristics that are not necessarily transferable to other industries. Clearly, our findings can be broadly generalized to the life science industry, of which the size and economic importance alone justifies this study. Yet, it is important to consider to what extent the reasoning and findings presented in this paper extend to other industries as well. It seems justified to suggest that the difficulty of generating innovations that are both technologically different and superior in customer-need fulfillment is valid in other technology-intensive (TI) industries, including the IT, semiconductor, and telecommunications industries. In all these industries, firms have to cope with a fast technological pace that goes along with uncertainty about the promising technologies that will deliver superior performance. They need to balance internal knowledge development with external knowledge sourcing, and their choice of investing in knowledge domains parallels the above described real-option analogy (Iansiti and West 1997). We therefore expect our results to be valid in other TI industries and less so in low-tech industries, but there is a clear need for further research to verify the robustness of our findings across knowledge-intensive industries.

Also, we focused only on products that have successfully traveled the long path towards FDA approval. We had no data on failed products, even though such information would be useful for further understanding the (in)effectiveness of drivers of new product innovation. Concretely, this implies that all drugs in our database satisfy minimum conditions of safety and efficacy. Extending this study to other, less regulated industries would be one way to relax this data restriction.

Finally, an implicit assumption underlying this study is that pharmaceutical firms are primarily interested in pursuing innovations that are technologically novel and/or superior in customer-need fulfillment. This assumption is supported by industry literature and individual firm reports. Yet, pharmaceutical firms may also have an incentive to develop incremental innovations, for example, to lengthen the relatively short duration of patent protection. Our random-effects approach may capture variation in firms' tendency to pursue incremental innovations, but it would be worthwhile for future research to explicitly study the role of incremental innovations.

To conclude, we hope that the empirical evidence we provide on the multidimensionality of radical product innovation will trigger more research projects in this area. Despite the limitations of this study, we find clear indications that it is worthwhile to disentangle different dimensions of product innovation. Also, our findings illustrate the importance of accounting for both internal and external sources of knowledge when studying innovation in knowledge-intensive industries. ■

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Notes

1. An example of the first is Bayer's Precose, approved in 1995 as a technologically novel drug for diabetes patients, but whose value over previous drugs is limited to side-effects. An example of the second is Schering Corporation's Intron-Rebetol therapy of hepatitis C, which is superior to alternative drugs, but is based on the combined use of Intron and Rebetol and not on a novel technology or active ingredient.

2. In view of its contributions, this study addresses one of the top-tier priority topics identified by the Marketing Science Institute, namely growth, innovation, and new products, with a particular focus on the subtopics of greatest interest being (1) developing radical innovation in existing industries and (2) generating innovative thinking and ideas.

3. Our conceptualization has implications for the locus of innovation, as technological novelty is restricted to novel changes in the core components of a new product (for a discussion of the locus of innovation, see Gatignon et al. 2002).

4. Hereafter, NPD process stands for the process that starts with a research phase in a specific customer application context and ends with product launch.

5. Based on personal communication with managers at Novartis Corporate Strategy, Switzerland.

6. The lengthy process of information gathering required to understand a product's relative customer benefits compared to alternative technologies has also been discussed in other literatures, including the search and uncertainty resolution literature (e.g., Lippman and McCardle 1991; Mamer and McCardle 1987) and the decision analysis literature (e.g., North and Stengel 1982).

7. In a more abstract and general sense, when low-outcome draws can be discarded at low cost, greater diversity of draws increases the expected value of the draws that are adopted (Gavetti and Levinthal 2000).

8. An identical approach has been used in a recent report by the National Institute for Health Care Management (2002) for distinguishing different dimensions of innovation, with drugs that are labeled both (1) a new molecular entity and (2) a high therapeutic-potential drug being categorized as the most innovative drugs.

9. Subsequent clinical tests indicated a significant benefit in reducing heart attacks and stroke (see Pfizer's 2002 Annual Report). Recently, clinical tests have been conducted to test if the same mode of action or active ingredient can also be usefully applied to other therapeutic classes such as Alzheimer's disease.

10. The positive effect for 1996 may be due to the Clinton administration's request to the FDA to intensify its approval processes.

11. Note that reliance on prior knowledge reflects the reverse of a unique knowledge base, hence the negative effect is consistent with the argument that a unique knowledge base aids in developing technologically novel products. Similarly, the negative effect of the interaction effect with portfolio diversity should be interpreted this way.

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