

Portfolios of Interfirm Agreements in Technology-Intensive Markets: Consequences for Innovation and Profitability

Despite the high relevance of firms' portfolios of upstream interfirm agreements in technology-intensive markets, little is known about their impact on innovative success. The authors develop a conceptual framework that explains the consequences of different portfolio descriptors for radical innovation, incremental innovation, and profitability. An empirical test in the pharmaceutical industry shows strong support for the developed theory.

There is a rich tradition in marketing of studying diverse aspects of innovation and new product development (NPD). A broad range of prior marketing studies have identified several drivers of NPD, such as the voice of the customer (Griffin and Hauser 1993), internal knowledge development (Madhavan and Grover 1998; Moorman and Miner 1997), and organizational processes and capabilities (Moorman 1995; Moorman and Slotegraaf 1999; Tatikonda and Montoya-Weiss 2001). Marketing scholars only recently have acknowledged an important additional driver: interfirm cooperation (Rindfleisch and Moorman 2001; Sivadas and Dwyer 2000). As Wind and Mahajan (1997, p. 7) point out, firms look beyond their boundaries to access knowledge required for NPD: "Typically, NPD activities are internally focused. Yet, the increased complexity and cost of developing truly innovative products and advances in new technologies often require expertise that the firm does not have; thus, [research-and-development] strategic alliances have emerged."

Especially in technology-intensive (TI) markets, to develop new products, firms need to cooperate with other firms through flexible upstream agreements (Sivadas and Dwyer 2000). However, most recent research has concentrated on interfirm agreements in isolation, with special

attention to dyadic information transfer and coordination (Sivadas and Dwyer 2000) and relational embeddedness (Rindfleisch and Moorman 2001). We build on this prior literature and develop a conceptual framework of the nature of knowledge transfer that occurs through portfolios of research-and-development (R&D) agreements rather than through individual isolated agreements. The importance of such agreement portfolios for NPD lies in their facilitating role in the access to and transfer of knowledge (Glazer 1991; Powell, Koput, and Smith-Doerr 1996). We focus on upstream R&D agreements, because these are the agreements that reportedly aid in innovation (Sivadas and Dwyer 2000; Wind and Mahajan 1997). Our focus on the entire portfolio of R&D agreements in which a firm is engaged enables us to capture descriptors that cannot be captured by studying agreements in isolation. We show that the portfolio descriptors have an important impact on a firm's innovative success.

A portfolio approach to interfirm cooperation corresponds with the importance that firms in many TI markets attach to portfolios of R&D agreements (Dutta and Weiss 1997). Industry observers conclude that firm performance in TI markets, such as the pharmaceutical industry, is strongly determined by successful management of entire portfolios of interfirm agreements (e.g., Slowinski 2001). For example, Pfizer has assembled a large portfolio of R&D agreements and claims that these efforts will have a positive impact on innovative output (Humphreys 2002). However, a recent article in *McKinsey Quarterly* (Bamford and Ernst 2002) reveals the difficulties that managers face when they try to assess their agreement portfolio's payoff to the firm.

We study the effect of portfolio characteristics on both radical and incremental innovation. When innovations incorporate a substantially different core technology and provide substantially greater customer benefits than previous products in the industry, we call them "radical" (Chandy and Tellis 1998); when one or both of the conditions are not met, we call them "incremental." We also study the impact of radical and incremental innovation on profitability, and we study whether the portfolio characteristics have addi-

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tional direct effects on profitability. In doing so, we account for possible cost and other implications that portfolio characteristics may have on profitability, in addition to their indirect effect through innovation.¹

We present an empirical test in the pharmaceutical industry. The test provides strong support for the developed theory but also yields some notable unexpected insights. In what follows, we first present the conceptual framework, hypotheses, and methodology. We then discuss our findings as well as theoretical and managerial implications. We conclude by acknowledging the limitations of our study and proposing several areas for further research.

Conceptual Framework and Hypotheses

In many industries, firms form R&D agreements to access knowledge from other firms, which may aid in innovation (Baum, Calabrese, and Silverman 2000; Powell, Koput, and Smith-Doerr 1996; Wind and Mahajan 1997). As such, a firm's portfolio of agreements affects its exposure to external knowledge and its opportunities for the transfer of that knowledge, which in turn affect innovation and profitability.

We focus on two specific descriptors of the R&D agreement portfolio: the portfolio's technological diversity and the level of repeated partnering. *Technological diversity* refers to the extent to which the agreements in a firm's portfolio cover a diverse set of technologies and thus may facilitate the inflow of more-diverse knowledge. *Repeated partnering* refers to the extent to which a firm engages in different R&D agreements with the same partners and thus may enable the transfer of more-complex knowledge (i.e., facilitate the inflow of knowledge in depth). These two characteristics are important for several reasons. First, they are theoretically more interesting than a popular but crude portfolio descriptor that is often mentioned in industry reports, namely, portfolio size. Technological diversity and repeated partnering facilitate knowledge transfer along two dimensions that have received considerable attention in prior literature (Dewar and Dutton 1986; Katila and Ahuja 2002): knowledge diversity (see Cohen and Levinthal 1990; Sinkula 1994) and knowledge depth (see Badaracco 1991; Hansen 1999).

Second, experts point to the importance of the agreement portfolio descriptors in TI markets, and in the pharmaceutical industry in particular (Bamford and Ernst 2002; Baum, Calabrese, and Silverman 2000; Gomes-Casseres 1998). Third, the two characteristics are within the managers' reach with respect to both monitoring and managing the portfolio, and thus they may serve as building blocks for a portfolio strategy. Fourth, there is substantial variation in the portfolio descriptors among different firms in TI markets. For example, there is substantial variation in pharmaceutical firms' portfolios of R&D agreements in terms of both technological diversity (e.g., Becton, Dickinson has

allied several times on immunoassay technology, but Syntex rarely allies twice on the same technology) and repeated partnering (e.g., Sandoz has allied several times with the biotechnology firm SyStemix, but Johnson & Johnson rarely allies twice with the same biotechnology firm).

We propose hypotheses on the effects of technological diversity and repeated partnering on (radical and incremental) innovation, after which we turn to their effects on profitability. We conclude this section with an overview of other relevant variables (e.g., portfolio size) for which we control.

Agreement Portfolios and Innovation

Technological diversity. A diverse inflow of knowledge affects innovation because it strengthens assimilative powers and enables novel associations (Cohen and Levinthal 1990). The inflow also stimulates broader perspectives and synthesis (Dewar and Dutton 1986; Fichman and Kemerer 1997). We expect that technological diversity affects both radical and incremental innovation.

We first consider radical innovation. Radical innovations are built on new (different from the established) technologies (Dewar and Dutton 1986) and often rely on the integration of different technologies (Iansiti and West 1997); thus, access to diverse knowledge bases is important. Greater technological diversity may lessen a firm's tendency to capitalize on or to be locked into its prior knowledge, and it may stimulate the firm to experiment with new technologies (Chandy and Tellis 1998). Especially in TI markets, which are characterized by rapid technological change, it is imperative for firms to keep abreast of the latest technological developments (Iansiti and West 1997). In this sense, a technologically diverse agreement portfolio facilitates access to new and nonredundant knowledge bases, which will aid in tracking new scientific discoveries and advances. Firms that access highly redundant knowledge bases are less open to and may even be unaware of other new promising technologies (Rowley, Behrens, and Krackhardt 2000). Their restrictive focus on a limited set of technologies makes it increasingly difficult to detect and engage in new promising technologies (Leonard-Barton 1992; Levinthal and March 1993), which may significantly hamper radical innovation in markets that are characterized by rapid technological change (Tushman and Anderson 1986).

In summary, we expect that technological diversity enhances radical innovation. It could be argued that a potential drawback of technological diversity is that it may impede a clear focus and complicate the development of specialist competence, which may constrain innovation. However, we expect that in TI markets, the positive effects of technological diversity dominate.

As for incremental innovation, the mere quantity of incoming information may be more relevant than its novelty. Firms can also arrive at incremental innovations without accessing novel information and without integrating different technologies. A diverse background provides a more robust basis for learning in TI markets (Iansiti and West 1997), because incoming information more likely is associated with what is already known. A more diverse technological background thus provides the firm with the ability to react to more new opportunities for innovation based on

¹Several of the relationships under study are also on the 2002–2004 Marketing Science Institute research priority list (e.g., valuation of innovation, developing radical innovation, alliances and partnerships), which indicates the high relevance of the topic.

external knowledge (Cohen and Levinthal 1990; Henderson and Cockburn 1994). Given that this rationale relies on the number rather than the novelty of opportunities, we also expect that technological diversity enhances incremental innovation. In summary:

H₁: Greater technological diversity of a firm's portfolio of interfirm R&D agreements enhances the firm's (a) radical innovation and (b) incremental innovation.

Level of repeated partnering. A general benefit of repeated agreements with the same partners is that the focal firm comes to know its partners better, which may enhance its ability to assess its partners' capabilities and consequently identify new opportunities for cooperation. As such, frequent cooperation with the same partner can generate a unique source of information about potential new opportunities (Gulati 1999). We expect that the benefit of repeated partnering leading to better identification of new opportunities enhances both incremental and radical innovation.

Repeated partnering also generates an advantage that is specifically related to radical innovations. Radical innovations encompass major improvements over existing products and therefore benefit from *complex* (i.e., tacit and interdependent) knowledge transfer (Iansiti and West 1997; Zucker, Darby, and Armstrong 2002). The average scientific discovery is not codified, which illustrates the significance of the tacit component of knowledge in TI markets (Zucker, Darby, and Armstrong 2002). Frequent and repeated interaction facilitates the transfer of tacit knowledge (Hansen 1999) and generates a deeper understanding of new technologies and innovations (Dewar and Dutton 1986; Fichman and Kemerer 1997). Repeated interaction allows for the emergence of relationship-specific heuristics (Uzzi 1997) and induces shared mental models (Madhavan and Grover 1998).² These heuristics and shared mental models in turn facilitate the process of assimilating complex knowledge (Polanyi 1966). The effective assimilation of complex knowledge in turn facilitates radical innovation. In short, we expect the following:

H₂: Higher levels of repeated partnering of a firm's portfolio of interfirm R&D agreements enhance the firm's (a) radical innovation and (b) incremental innovation.

Note that in line with this reasoning, support for H_{2a} and H_{2b} would indicate that repeated partnering effectively drives the identification of new opportunities, but support for only H_{2a} would indicate that repeated partnering primarily facilitates the transfer of tacit knowledge.

Agreement Portfolios and Profitability

We expect not only that the portfolio characteristics, through their impact on knowledge access and transfer, affect radical and incremental innovation but also that they have additional direct effects on profitability. We distinguish between demand- and supply-side effects of agreement portfolio characteristics on profitability.

²The argument relies on the frequency of partnering between two actors (see, e.g., Hansen 1999) and does not imply an underlying time dimension.

First, agreement portfolios affect the demand side of profitability through the stock of radical and incremental innovations they generate. Innovations are often credited for generating sales growth and thereby aiding profitability. In addition, it can be expected that radical innovations are more profitable than incremental innovations, because they represent significant advances in customer benefits, among other reasons. Second, agreement portfolios affect the supply side of profitability. As we argue subsequently, the technological diversity and level of repeated partnering of a firm's R&D agreement portfolio influence the costs of partnering as well as the firm's ability to extract rent from the agreements.

Demand Side: Stocks of Radical and Incremental Innovations and Profitability

Over time, firms build stocks of radical and incremental innovations. Higher levels of innovation enhance a firm's profitability (Geroski, Machin, and Van Reenen 1993). However, it is not clear whether this is true to the same extent for a firm's stock of radical innovations and its stock of incremental innovations. The general belief in marketing is that radical innovations disproportionately contribute to profitability (Wind and Mahajan 1997). The underlying rationale follows directly from the definition of radical innovations. First, radical innovations offer significant improvements over existing alternatives in terms of need satisfaction and thus may trigger higher demand. Second, radical innovations are based on new and complex technologies and are thus more difficult for competitors to imitate (Dutta, Narasimhan, and Rajiv 1999). We hypothesize the following:

H₃: A firm's stock of radical innovations and its stock of incremental innovations enhance profitability.

H₄: The effect of a firm's stock of radical innovations on profitability is greater than the effect of a firm's stock of incremental innovations on profitability.

Supply Side: Agreement Portfolio Composition and Profitability

We now turn to the supply-side effects of the portfolio characteristics on profitability in addition to their indirect demand-side effect through (stocks of) radical and incremental innovations. These effects are grounded in cost and rent-extraction rationales.

Technological diversity. Higher levels of technological diversity require higher costs. The cost of building a minimum level of knowledge (unit-one cost) is typically very high (John, Weiss, and Dutta 1999). Therefore, firms that develop a broad technological background typically face higher costs (Gatignon and Xuereb 1997). For example, in the pharmaceutical industry, to a large extent, strategic decision making is determined by the high costs required to acquire new technologies, as is illustrated by Guidant's difficulties in deciding whether to engage in radiation therapy for the treatment and prevention of restenosis (Roberts 2001). Not only was there a great deal of uncertainty about the effectiveness of radiation therapy, but an initial investment cost was estimated at anywhere between \$60 million and \$100 million. Firms' building a portfolio of R&D agreements that covers a large diversity of technologies may con-

siderably enhance the total investment costs. In contrast, making further advances in technology classes in which the firm is already active requires fewer additional investments than advances in technology classes that are new to the firm. Thus, concentration of the agreement portfolio around fewer technologies may be more cost efficient than diversification of the agreement portfolio over a wide set of technologies.

H₅: When the level of innovation is controlled for, greater technological diversity of a firm's portfolio of interfirm R&D agreements lowers the firm's profitability.

Level of repeated partnering. The literature offers different rationales for the direct impact of repeated partnering on profitability in addition to its indirect impact through innovation. Repeated partnering may contribute to cost efficiency. Cooperation with the same partner is cheaper than cooperation with a new partner. In the context of industrial purchasing relationships, Stump and Heide (1996) find that partnering with the same partner is cost-efficient because previous qualification efforts reduce the need for new qualification and monitoring practices. In other words, firms are able to examine their prior partners' capabilities (Håkansson 1993). In this sense, a major risk factor to agreements (i.e., the extent to which the partner is capable of doing what it claims to be able to do) is minimized, which may represent a substantial saving of time and money lost in contracting with the wrong partner. However, this positive relationship is unlikely to be linear. Prior research has shown that firms' cooperating too frequently with the same partners may result in more attention for relationship maintenance and loyalty than for the economic outcomes of cooperation. In other words, firms' cooperating too frequently with the same partners can stifle effective economic action if social aspects supersede economic imperatives (Uzzi 1997). As a result, levels of repeated partnering that are too high can cause a decline in profitability.³ We posit the following:

H₆: When the level of innovation is controlled for, the level of repeated partnering of a firm's portfolio of interfirm R&D agreements has an inverted U-shaped effect on the firm's profitability.

Other Variables

In addition to the relationships posited previously, we control for other variables that may affect radical innovation, incremental innovation, and profitability but that are outside our theoretical focus.

Portfolio size. Portfolio size refers to the number of R&D agreements that make up a portfolio and, in general, is considered to facilitate obtaining more exposure to knowledge bases (see, e.g., Dewar and Dutton 1986). Previous studies have documented the positive impact of portfolio size on innovation (Powell, Koput, and Smith-Doerr 1996; Shan, Walker, and Kogut 1994). Large portfolios lead to

scale effects in development (Ahuja 2000) and facilitate firms gaining more exposure to knowledge from external sources (Dewar and Dutton 1986). However, portfolio size's effect on radical innovation is not clear. As for profitability, firms' greater experience with interfirm agreements has been associated with positive firm outcomes (Powell, Koput, and Smith-Doerr 1996). The large number of agreements provides the firm with a broad repertoire of experiences that result from previous trials and tribulations (Anand and Khanna 2000). The resulting experience effects not only enhance cost efficiency of cooperation but also make firms better able to extract rent from their agreements (Gulati, Nohria, and Zaheer 2000), which both contribute to profitability.

Resident knowledge. A firm's portfolio of R&D agreements provides insight into its access to external knowledge bases and subsequently into its ability to generate innovations. However, in the process of turning knowledge into actual innovative products, other variables come into play. Firms should be able not only to detect and absorb relevant new technologies and new knowledge but also to apply this knowledge effectively (as formalized in the absorptive capacity argument; Cohen and Levinthal 1990). We expect that a firm's resident knowledge has a positive effect on both innovation and profitability, because it is likely to aid in all processes of detection, absorption, and application.

Experience. In the radical and incremental innovation equations, we also control for a firm's prior experience in developing radical and incremental products, respectively. Prior experience reflects the processes that the firm has in place to innovate successfully. Firms with internal organizational processes that have facilitated radical and incremental innovation in the past are more likely to generate new radical and incremental innovations in the future.

R&D expenditures. Another variable that may influence innovation and profitability is the level of a firm's R&D expenditures. We expect that firms that devote more resources to R&D are more successful with respect to innovation and profitability.

Sales expenditures. In the profitability equation, we further control for sales expenses. In the pharmaceutical industry, the setting of our empirical study, direct selling through medical representatives is by far the most influential marketing instrument (Parsons and Vanden Abeele 1981); there were more than 80,000 sales representatives in the field in 2001 (Shalo 2002). We expect that sales expenditures have a positive effect on profitability.

Trend and industry shocks. Previous studies suggest that the growth of the biotechnology industry has led to more intense competition (Zucker, Darby, and Brewer 1994). We expect that this increasing competitive intensity will be reflected in a negative time trend in the innovation and profitability equations. Apart from a linear industry trend over the entire observation period, there may have been other events that occurred in specific years that affected the outcome variables. We include year dummies to control for such exogenous shocks, and we retain the ones that have a

³Note that this argument provides a novel interpretation of what Grayson and Ambler (1999) refer to as the "dark side" of strong ties. We suggest that the downside of strong ties lies in their restrictive effect on economically optimal behavior.

significant impact on the outcome variables in the final model.

Firm size. Much prior research in economics has addressed the relationship between firm size and innovation, building on the seminal work of Schumpeter (1942). Academic research investigating this relationship has found positive, negative, and insignificant size effects (Chandy and Tellis 2000; Cohen and Levin 1989). As for profitability, we expect larger firms to make more profits, in an absolute sense, merely because of a scale effect.

Methodology

Empirical Setting

The empirical setting of our study is the pharmaceutical industry. In particular, we examine the effect of a pharmaceutical firm's portfolio of agreements with biotechnology firms on innovation and profitability. The discoveries of recombinant DNA (by Cohen and Boyer in 1973) and cell fusion (by Kohler and Milstein in 1975) gave rise to the modern biotechnology industry. Pharmaceutical firms reacted to the biotechnology revolution by building portfolios of upstream R&D agreements with biotechnology firms to access new scientific and technological developments (see, e.g., Pisano 1990).

There are several reasons we chose this context. First, the pharmaceutical industry is a TI industry in which scientific knowledge plays a focal role. Second, interfirm cooperation in the pharmaceutical industry boomed with the rise of biotechnology, especially since the second half of the 1980s. From 1985 on, interfirm agreements with established pharmaceutical firms have overtaken venture capital as the main form of financing the biotechnology industry (Zucker, Darby, and Brewer 1994). At the end of the 1990s, R&D agreements between pharmaceutical firms and innovative biotechnology firms provided eight times more capital to U.S. biotechnology firms than did initial public offerings (Enrriquez 1998). As we described previously, pharmaceutical firms developed portfolios of R&D agreements with substantial variation in their composition. Third, secondary data are available on all interfirm agreements between pharmaceutical firms and biotechnology firms in the United States since 1985 (i.e., from the inception of alliance activity in the biotechnology industry).

Data Collection

We collected data to test our theoretical predictions from four different sources. First, we collected data on pharmaceutical firms' upstream R&D agreements with biotechnology firms from the Recombinant Capital database. This database covers all such upstream R&D agreements from 1985 until the present. It provides information on the identity of the parties to the agreement, the nature of the agreement, and the technologies that the agreement covers (categorized into 42 technological classes). Recombinant Capital is a consulting firm that specializes in biotechnology alliances; it is based in the San Francisco Bay Area and was founded by a former manager of business development at

Chiron. Recombinant Capital's clients include more than 150 biotechnology and pharmaceutical firms, as well as several universities and investment banking and venture firms active in the biotechnology area. Recombinant Capital uses several sources to ensure the accuracy of its database: trade literature, press releases, and its close links and interactions with experts involved in biotechnology in the pharmaceutical industry.

Second, we collected data on new drugs from the drug approval list of the Food and Drug Administration (FDA). This list provides all drugs approved by the FDA and is updated weekly. Moreover, in this list, the FDA provides additional useful information about each drug, namely, its therapeutic potential and chemical type. We use this additional information to distinguish radical drugs from incremental drugs.

Third, we collected data on profitability, firm size, sales expenses, and R&D expenses from the Compustat database. Fourth, we collected data on biotechnology patents and patent citations from the U.S. Patent and Trademark Office database.

The database we compiled from the four sources contains yearly data on the agreement portfolios of 58 publicly traded pharmaceutical firms from 1985 to 1998. In total, our database covers 991 R&D agreements. For each year (1985–1998) and pharmaceutical firm, the database also contains information on profits, size, sales expenses, R&D expenses, and citation-weighted patents. We used data on new drugs from 1991 to 1999. Before 1991, the FDA did not provide the detailed and complete drug information required for our study (for sample descriptives, see Table 1).

Measurement

Dependent variables. We measured *radical innovation* of firm i in year t ($RADINNOV_{it}$) as the total number of new radical drugs of firm i that received FDA approval in year t . Given that radical drugs should both provide substantially higher customer benefits than previous drugs in the industry and incorporate a substantially different core technology (or active ingredient) (Chandy and Tellis 1998, 2000), we base our radicalness distinction on two drug properties provided by the FDA: a drug's therapeutic potential and its chemical type. First, the FDA (2002) categorizes all new drugs according to their treatment potential and distinguishes between standard ("therapeutic qualities similar to those of an already marketed drug") and high-potential ("an advance over available therapy") drugs. Second, the FDA assigns a chemical type to each drug. Only drugs of Chemical Type 1 represent a new technology (i.e., different from the established technologies); they involve an "active ingredient that has never been marketed" (see FDA 2002). We refer to all drugs that are labeled both high-therapeutic-potential drugs and Chemical Type 1 drugs as radical drugs. In total, 13.7% of the newly approved drugs in our database are labeled radical drugs, which compares favorably with cross-industry estimates (i.e., approximately 10%; see Wind and Mahajan 1997) and with a recent study in the pharmaceutical industry by the National Institute for Health Care Management (15%; Wechsler 2002).

TABLE 1
Sample Characteristics

	Minimum	Maximum	Average	Standard Deviation
Repeated partnering	0	.88	.22	.18
Technological diversity	.24	.93	.70	.16
Portfolio size	0	84	6.33	11.57
Number of radical drugs (per year)	0	2	.09	.33
Number of incremental drugs (per year)	0	8	.54	1.16
Profitability (in 10 ⁶ \$)	-756.15	6821.7	494.90	910.77
Firm size (in 10 ³)	.015	151.9	20.89	26.26
R&D expense (in 10 ⁶ \$)	0	4435	399.05	631.37
Selling, general, and administrative expense (in 10 ⁶ \$)	1.63	15877	1700.02	2547.20

We measured *incremental innovation* of firm *i* in year *t* (INCINNOV_{it}) as the total number of new incremental drugs of firm *i* that received FDA approval in year *t*. All drugs that do not satisfy both radicalness conditions (high therapeutic potential and Chemical Type 1) are labeled incremental drugs.

We measured *profitability* of firm *i* in year *t* (PROFIT_{it}) as the net income of firm *i* in year *t*. Profitability is the net income (loss) variable provided by Compustat.

Independent variables. We measured the *technological diversity* of a firm's agreement portfolio (TECHDIV_{it}^{cum})⁴ as follows (see Powell, Koput, and Smith-Doerr 1996): For firm *i* up to year *t*, we denote the number of times that the firm's agreements cover technology *j* as *n*_{it,j} (*j* = 1 ... 42).⁵ Then, *p*_{it,j} = *n*_{it,j}/∑_j*n*_{it,j} represents the proportion of occurrence of technology *j* relative to the cumulative occurrence of all technologies in firm *i*'s portfolio. We square each *p*_{it,j} and then take the sum over all technologies *j*; we subtract the sum from 1, which results in the index of technological diversity:

$$(1) \quad \text{TECHDIV}_{it}^{\text{cum}} = 1 - \sum_{j=1}^J p_{it,j}^2$$

The technological diversity index equals zero when a firm allies on only a single technology, and it is close to one when a firm spreads its alliance activity over many technologies. An example further clarifies how this measure behaves: Suppose that two firms (A and B) both have a portfolio of four agreements. The agreements of Firm A involve three different technologies (Agreements 1 and 2 involve technology *x*; Agreement 3 involves technology *y*; Agreement 4 involves technology *z*), and the agreements of Firm B involve two different technologies (Agreements 1 and 2 involve technology *x*; Agreements 3 and 4 involve technology *y*). It is easily computed that Firm A has a technological diversity of .625, and Firm B has a technological diversity of .5. In a sense, this measure is similar to Hirschman–

Herfindahl indexes in the economics literature (which are typically used to measure market concentration as the sum of squared market shares).

Repeated partnering (REP_{it}^{cum}) is a ratio that measures the extent to which firms cooperate with the same partners in a given period of time.⁶ For firm *i* up to year *t*, we denote the number of different partners in its agreement portfolio as *P*_{it}^{cum} and the number of agreements as *A*_{it}^{cum}. We then define repeated partnering of firm *i* up to year *t* as

$$(2) \quad \text{REP}_{it}^{\text{cum}} = 1 - (P_{it}^{\text{cum}} / A_{it}^{\text{cum}})$$

The index of repeated partnering equals zero when a firm never cooperates twice with the same partner, and it is close to one when the firm cooperates frequently with the same partner. In the stylized example of Equation 1, if Firm A cooperates with three different partners and Firm B with two different partners, Firm A's level of repeated partnering is .75, and Firm B's level of repeated partnering is .5.

Finally, we measured a firm's *stock of incremental innovations* (INCSTOCK_{it}^{cum}) as the cumulative number of incremental innovations (INCINNOV_{it}) from 1991 until year *t*. Similarly, we measured a firm's *stock of radical innovations* (RADSTOCK_{it}^{cum}) as the cumulative number of radical innovations (RADINNOV_{it}) from 1991 until year *t*.

Control variables. We measured portfolio size of firm *i* in year *t* (PORFSIZE_{it}^{cum}) as the total number of R&D agreements, *A*_{it}^{cum}, of firm *i* from 1985 up to year *t*. We measured the amount of resident knowledge as the citation-weighted biotechnology patent counts, corrected for truncation bias (Dutta and Weiss 1997; Griliches 1990; Trajtenberg 1990). The U.S. Patent and Trademark Office provides detailed information on all biotechnology-related patents (at year *t*), including the number of times the patents have been cited in a given year (*t* + 1, *t* + 2, ..., *T*). We included all patents from 1975 (the year in which the citations were registered first) and on, and we constructed a cumulative variable PATENT_{it}^{cum}. We corrected the measure for truncation as follows (see also Hall, Jaffe, and Trajtenberg 2001): For early

⁴The cumulative (up to year *t*) character of a variable is indicated with the superscript "cum."

⁵One agreement can cover multiple technologies; one biotechnology firm can have multiple technologies in-house.

⁶This index measures the extent to which firms cooperate with the same partners (i.e., it does not necessarily refer to relational history).

patents at Time t_0 , we calculated the average citation pattern (the number of times the patents are cited) over the period $[t_0 + 1; T]$. More specifically, for each year $t \in [t_0 + 1; T]$, we derived the proportion of all citations for the patents that occurred in the period $[t_0 + 1; t]$. For more recent patents (e.g., in year 1996), we had citation data for only a limited number of years. For these recent patents, we calculated the expected number of citations in the future by extrapolation, on the basis of the total number of citations that already occurred in the first years and assuming that the citation pattern is similar to that for early patents.

As proxies for a firm's experience with radical and incremental innovation, we include $RADSTOCK_{it-1}^{cum}$ and $INCSTOCK_{it-1}^{cum}$ in the respective innovation equations. These lagged variables reflect the processes that are set by the firm to generate innovations.

Furthermore, the Compustat database contains measures on sales expenses ($SALESEXP_{it}$), R&D expenses ($R\&D_{it}$), and firm size ($FIRMSIZE_{it}$). Note that sales expenses are represented in Compustat as sales, general, and administrative expenses. We measure firm size as the number of employees.

Findings

Model Estimation

Radical and incremental innovation models. We measured radical innovation of firm i at time t as the total number of radical drugs of firm i approved by the FDA at time t ($RADINNOV_{it}$). We estimated a negative binomial maximum-likelihood regression model, which is an appropriate specification in view of the count character of the dependent variable and the relatively large number of zeros (which are a natural and relevant outcome of the count process). In our case, a (simpler) Poisson specification was not appropriate because of overdispersion.⁷ The underlying assumption of the Poisson model of equality of conditional mean and variance functions is violated, which leads to inefficient Poisson estimates.

As explanatory variables, we included $TECHDIV_{it-1}^{cum}$ and REP_{it-1}^{cum} . We measured all portfolio descriptors (technological diversity, repeated partnering, and size) at time t over the cumulative portfolio up to year t (Dutta and Weiss 1997). There is likely a lag between firms' partnering activities and the resulting innovative output. Although the cumulative variables partly account for this, we lagged all our portfolio characteristics with one period. We also lagged the control variables with one period. We control for $PORFSIZE_{it-1}^{cum}$, $RADSTOCK_{it-1}^{cum}$, $PATENT_{it-1}^{cum}$, $TREND$, year dummy variables, $R\&D_{it-1}$, and $FIRMSIZE_{it-1}$.

We measured incremental innovation of firm i at time t as the total number of incremental drugs of firm i approved by the FDA at time t ($INCINNOV_{it}$). As in the radical innovation model, we estimated a negative binomial model for the incremental innovation equation, with $TECHDIV_{it-1}^{cum}$ and REP_{it-1}^{cum} as explanatory variables. We controlled for $PORFSIZE_{it-1}^{cum}$, $INCSTOCK_{it-1}^{cum}$, $PATENT_{it-1}^{cum}$, $TREND$, year dummy variables, $R\&D_{it-1}$, and $FIRMSIZE_{it-1}$. Table 2 presents a correlation matrix of our portfolio descriptors.

Profitability model. We measured profitability of firm i at time t as the net income of firm i at time t ($PROFIT_{it}$). Because $PROFIT_{it}$ is a continuous variable, we used an ordinary least squares regression specification in which we regressed $PROFIT_{it}$ on the variables $RADSTOCK_{it}^{cum}$, $INCSTOCK_{it}^{cum}$, $TECHDIV_{it-1}^{cum}$, REP_{it-1}^{cum} , $PORFSIZE_{it-1}^{cum}$, $PATENT_{it-1}^{cum}$, $TREND$, year dummy variables, $R\&D_{it-1}$, $SALESEXP_{it-1}$, and $FIRMSIZE_{it-1}$. In all equations, we mean-centered the independent variables. In line with intuition, we again lagged all independent variables, except for the stock of incremental and radical innovations, because new drugs already affect profitability in the introduction period.

Results

Table 3 presents the estimation results for the radical and incremental innovation equations. Table 4 presents the estimation results for the profitability equation.

Radical and incremental innovation. Technological diversity positively influences both radical innovation ($\beta = 1.535$; $p < .001$) and incremental innovation ($\beta = .426$; $p < .05$), in support of H_1 . A more diverse portfolio strengthens a firm's basis for learning and enhances its absorptive capacity (Cohen and Levinthal 1990), thereby enabling it not to miss the most recent technological developments. As such, a technologically diverse portfolio enhances the firm's number of NPD opportunities and lowers the risk of lock-in with inferior technologies (Levinthal and March 1993).

We find that whereas repeated partnering enhances radical innovation ($\beta = .680$; $p = .001$), in support of H_{2a} , its effect on incremental innovation is not significant ($\beta = -.013$; $p = .927$), which rejects H_{2b} . This finding seems to indicate that repeated partnering serves as more of a facilitator for complex knowledge transfer than an aid for opening up new opportunities.

We also included several control variables in the innovation equations. First, portfolio size has a significant, positive effect on incremental innovation ($\beta = .252$; $p < .05$) but does not affect radical innovation ($\beta = .173$; $p = .350$). Apparently, despite the central place of the mere size of the port-

TABLE 2
Correlation Matrix Portfolio Descriptors

	TECHDIV	REP	PORFSIZE
TECHDIV	1.000		
REP	-.205	1.000	
PORFSIZE	.542	-.213	1.000

⁷In a negative binomial regression, the count variable is believed to be generated by a Poisson-like process, except that the variation is greater than that of a true Poisson (referred to as "overdispersion"). Although in a case of overdispersion the Poisson model still provides consistent estimates, the standard errors are underestimated. The negative binomial model we use does not suffer from this problem.

TABLE 3
Innovation Equations

Variable	Radical Innovation Equation (RADINNOV)				Incremental Innovation Equation (INCINNOV)			
	Parameter Estimate	Standard Error	z-Value	p-Value (Two-Tailed)	Parameter Estimate	Standard Error	z-Value	p-Value (Two-Tailed)
TECHDIV	1.535	.430	3.57	.000	.426	.172	2.48	.013
REP	.680	.196	3.47	.001	-.013	.144	-.09	.927
PORFSIZE	.173	.185	.93	.350	.252	.111	2.27	.023
RADSTOCK(-1)	.231	.173	1.34	.181	—	—	—	—
INCSTOCK(-1)	—	—	—	—	.380	.130	2.91	.004
PATENT	.019	.137	.14	.891	-.093	.084	-1.10	.269
TREND	-1.736	.531	-3.27	.001	-1.024	.233	-4.39	.000
DUMMY96	1.189	.341	3.49	.000	.646	.222	2.91	.004
R&D	.491	.264	1.86	.063	.313	.151	2.07	.038
FIRMSIZE	-.268	.268	-1.00	.317	.080	.129	.62	.536
Intercept	-2.688	.301	-8.94	.000	-.664	.132	-5.02	.000
Fit	Pseudo R ² = .25 Likelihood ratio χ^2 (9): 75.03; $p < .001$				Pseudo R ² = .17 Likelihood ratio χ^2 (9): 147.88; $p < .001$			
N	426				426			

TABLE 4
Profitability Equation

Profitability Equation (PROFIT)				
Variable	Parameter Estimate	Standard Error	t-Value	p-Value (Two-Tailed)
RADSTOCK	123.379	35.302	3.49	.001
INCSTOCK	2.145	44.953	.05	.962
TECHDIV	-73.400	34.901	-2.10	.036
REP	266.073	81.801	7.06	.000
REP ²	-141.050	29.892	-4.72	.000
PORFSIZE	300.231	42.516	7.06	.000
PATENT	35.084	21.621	1.62	.105
TREND	-171.252	41.675	-4.11	.000
R&D	44.759	88.964	.50	.615
SALESEXP	1085.487	118.178	9.19	.000
FIRMSIZE	-453.765	55.363	-8.20	.000
Intercept	617.782	28.837	21.42	.000
Fit	Adjusted R ² = .80 F(11, 443): 156.05; <i>p</i> < .001			
N	455			

folio in industry discourse, it provides access to more opportunities, but it does not provide the depth or diversity of knowledge that stimulates radical innovation. Second, we included the lagged stocks of innovations as indicators of the firm's prior experience with radical and incremental innovation. We find that both have the expected positive sign, but only the prior stock of incremental innovations is significant ($\beta = .380$; $p < .01$). The stock of prior radical innovations is not significant ($\beta = .231$; $p = .181$). A large stock of prior incremental innovations seems to aid in the development of new incremental innovations, whereas a track record of radical innovation is no guarantee for future success in radical innovation. Third, we controlled for resident knowledge using a citation-weighted patent variable. Surprisingly, this variable is not significant in both equations (radical: $\beta = .019$; $p = .891$; incremental: $\beta = -.093$; $p = .269$). Further exploration reveals a quadratic effect of patents on incremental innovation. More specifically, we find an inverted U-shaped effect (main term: $\beta = .439$; $p < .05$; quadratic term: $\beta = -.184$; $p < .01$). The role of patents requires further research. Fourth, we find a negative time trend in both the radical innovation ($\beta = -1.736$; $p = .001$) and the incremental innovation ($\beta = -1.024$; $p < .001$) equations. Furthermore, we find one year dummy variable (1996) to be significant; we retained this variable in both the radical innovation ($\beta = 1.189$; $p < .001$) and the incremental innovation ($\beta = .646$; $p < .01$) equations. Although the following is only a *post hoc* interpretation, the 1996 effect may result from the U.S. administration urging the FDA in early 1996 to speed up its approval procedures in major therapeutic classes (as reported on the *FDA News* Web site; Cruzan 1996). Finally, we find that the effect of R&D expenses is positive and significant in both innovation equations (radical: $\beta = .491$; $p < .10$; incremental: $\beta = .313$; $p < .05$). However, the effect of firm size is not significant in any of the two innovation equations (radical: $\beta = -.268$; $p = .317$; incremental: $\beta = .080$; $p = .536$).

Profitability. As for the profitability equation, we posited in H₃ that both a firm's stock of radical innovations and its stock of incremental innovations enhance profitability. We find only partial support for this, with a positive effect for the stock of radical innovations ($\beta = 123.379$; $p = .001$) and no significant effect for the stock of incremental innovations ($\beta = 2.145$; $p = .962$).⁸ In H₄, we hypothesized that the stock of radical innovations would have a greater positive effect on profitability than the stock of incremental innovations. A Wald test rejected the null hypothesis that the parameters are equal in size ($F = 3.168$; $p < .10$), so we can conclude that the effect of radical innovation indeed is greater than that of incremental innovation. We also conducted additional likelihood ratio tests that consistently point to the same conclusion.⁹

In accordance with H₅, we find a negative, direct effect of technological diversity on profitability ($\beta = -73.400$; $p < .05$). This negative effect indicates that firms have difficulties recouping the high initial investment costs required for a technologically diverse portfolio.

We posited in H₆ that repeated partnering has an additional inverted U-shaped effect on profitability. We find strongly significant main and quadratic effects in support of

⁸We also estimated the model with a ratio variable (per firm and year *t*) that measures the proportion of a firm's drugs that are radical. This ratio approach did not change any of the other results, and the ratio itself had a positive, though only marginally significant ($p = .141$), effect on profitability.

⁹We conducted likelihood ratio tests to study the extra variance explained by the stock of radical innovations and the stock of incremental innovations, respectively. Deletion of radical innovation from a profit model that includes incremental innovation significantly deteriorates the log-likelihood ($p < .01$), whereas omission of incremental innovation from a profit model that includes radical innovation does not significantly affect the log-likelihood.

H_6 (main term: $\beta = 266.073$; $p < .001$; quadratic term: $\beta = -141.050$; $p < .001$). Low levels of repeated partnering require substantial partner qualification costs, whereas high levels of repeated partnering restrict economically optimal behavior. When innovative output is controlled for, the optimum lies at medium levels of repeated partnering.

Finally, we included several control variables. First, we find a positive effect of portfolio size on profitability ($\beta = 300.231$; $p < .001$), in support of the argument that firms with larger portfolios enjoy experience effects that result in cost efficiency and better rent extraction. Second, the amount of resident knowledge has a (weak) positive effect on profitability ($\beta = 35.084$; $p = .105$). Third, as in the innovation equations, we find a negative time trend ($\beta = -171.252$; $p < .001$). However, none of the year dummies were significant, which further strengthens our interpretation that the 1996 effect in the innovation equations is related to a temporary extra effort by the FDA. For the other control variables—R&D expenditures, sales expenditures, and firm size—we respectively find no effect ($\beta = 44.759$; $p = .615$), a positive effect ($\beta = 1085.487$; $p < .001$), and a negative effect ($\beta = -453.765$; $p < .001$).

Robustness of Results

Time lags. In our model estimation, we lagged all explanatory variables, except for innovation stocks in the profit equation, with one year. We examined the sensitivity of our results by applying different lag structures (e.g., two years, three years); the focal results remain unchanged. Note that working with lagged cumulative independent variables further supports our notion of causality, in that a dependent variable at time T is explained by the entire portfolio from $t = 0$ up to $t = T - 1$.

Knowledge depreciation and appreciation. Another important issue is whether the value of knowledge changes over time. There are three possibilities: no change, depreciation, or appreciation. Although our analyses assumed that knowledge has a constant value, we also checked the robustness for changes in its value over time. On the one hand, a certain depreciation rate could be specified, which would enable knowledge to become worth less over time, which may be especially relevant in TI markets (Glazer and Weiss 1993). Prior literature typically uses a 20% depreciation rate (e.g., Henderson and Cockburn 1994). On the other hand, it could be argued that complex knowledge is not readily available for use immediately after assimilation and that knowledge becomes worth more as it becomes more embedded in the organization (e.g., Madhavan and Grover 1998). Such reasoning would suggest an appreciation rate rather than a depreciation rate. We estimated our model with depreciation/appreciation rates ranging from .8 to 1.2, and we found our results to be robust for knowledge depreciation and appreciation. Thus, our assumption that knowledge has a constant value does not affect our results.

Alternative model specifications. Finally, we tested alternative model specifications. We specified an ordered probit structure rather than the negative binomial for the innovation models. We also estimated nested models and models containing interaction effects to verify the robust-

ness of our findings. None of the exploratory efforts provided additional insights, and the posited theoretical effects were unaffected and remained similar to the ones we reported.

Implications

Our study has several implications for both theory development and practice. We discuss two major theoretical implications and two major managerial implications, respectively.

Theoretical Implications

Our detailed portfolio perspective contributes to both the marketing and the network literature. First, the marketing literature on innovation and NPD may benefit from our study in different ways. By taking a portfolio perspective, our study empirically substantiates a belief shared by many marketing scholars (Achrol 1997; Kotler, Jain, and Maesincee 2002), namely, that such a broadened perspective would significantly enhance the understanding of marketing phenomena in dynamic markets. Despite the shared understanding in conceptual work, empirical studies have been scarce (Stern 1996). Our study points to the importance of considering R&D agreements in TI markets not in isolation but from a portfolio perspective, which provides insight into a firm's ability to access diverse and complex knowledge bases. Thus, this study enriches prior work in marketing on the drivers of innovation. Although several studies have pointed to the importance of R&D capability for success in TI markets (Dutta, Narasimhan, and Rajiv 1999) and for product development broadly (e.g., Moorman and Slotegraaf 1999), the focus has been on internal processes and knowledge domains. Our findings suggest that access to external knowledge domains can also have an important bearing on a firm's ability to develop new products. Prior work has also acknowledged interfirm knowledge sharing as an important driver of innovation (Rindfleisch and Moorman 2001; Sivadas and Dwyer 2000). Our portfolio perspective extends this idea and shows that a holistic view that transcends the individual agreement is required to assess the success of a firm's overall efforts to share knowledge with industry partners.

Second, our study also contributes to the network literature. Recent network studies suggest that repeated and intense cooperation enhances the risk of lock-in with inferior technologies and myopia caused by higher knowledge redundancy (e.g., Rowley, Behrens, and Krackhardt 2000; Uzzi 1997). Our study shows that this rationale may be misleading in TI markets for two reasons. First, contrary to the seminal work in sociology on which this argument is based (Granovetter 1973), the knowledge that is transferred in TI markets does not consist of simple bits of information but has an important tacit component. Frequent cooperation with the same partners facilitates the transfer of tacit knowledge. Second, rather than consider repeated collaboration as a proxy for knowledge redundancy, we show how knowledge diversity can be accounted for more directly. The diversity of technologies that underlie the different agreements is a more direct approximation of the extent to which a firm is able to access nonredundant knowledge. Thus, we were not

surprised to find that for given levels of technological diversity, repeated partnering actually enhances radical innovation. On a related note, our findings suggest that in TI markets, both the benefits of nonredundant knowledge and its downside should be considered. Access to diverse or nonredundant knowledge requires high investment costs, and firms often have a difficult time recouping the initial investments. Our findings can help explain why other studies did not find a hypothesized negative relationship between knowledge redundancy and firm performance (see, e.g., Rowley, Behrens, and Krackhardt 2000).

Managerial Implications

Our study reveals how a firm's portfolio of agreements can be managed in accordance with different firm objectives. Our findings also further underscore the importance of radical innovation for profitability.

First, on the basis of our findings, we can provide managers with guidelines as to how to build an effective portfolio according to their specific objectives. We offer a set of useful portfolio descriptors that can be measured and managed when decision makers are prepared to look beyond the individual agreement. Whereas the industry literature overaddresses portfolio size, we provide a richer perspective and point to the importance of portfolio diversity and repeated partnering. Moreover, we acknowledge that firms may have different or multiple objectives (radical innovation, incremental innovation, and profitability), which may bring forth different challenges. As such, we recommend that firms that have the end objective of radical innovation invest in a technologically diverse portfolio to gain access to a diverse knowledge base in which it repeatedly contracts with the same partners to facilitate complex knowledge transfer. Companies that focus on the bottom line (profitability) should balance the demand-side advantages of radical innovations with the supply-side drawbacks of technological diversity and repeated partnering. It is important to note that firms can easily monitor and manage the portfolio descriptors we suggest.

Second, our study empirically underscores the importance of radical innovation and emphasizes the need to develop an appropriate R&D agreement portfolio for radical innovation. Firms should improve the balance between incremental and breakthrough innovation (Wind and Mahajan 1997), but they also may need to turn radical innovation into the core objective of their innovation strategies if their end goal is maximizing profits. Notably, we find that whereas prior experience with incremental innovations entails new incremental innovations, prior experience with radical innovations does not guarantee new radical innovations in the future.

Limitations and Further Research

As a first limitation, we note that our sample includes mainly large firms that are publicly traded. Although the sample is a good representation of the industry being studied, it may limit the generalizability of our results. We also focus on only one industry. An interesting area for further research would be to compare industries and test the gener-

alizability of the effects of different portfolio descriptors on performance.

Although we take into account the identity and knowledge domains of a focal firm's partner firms, there may be several other partner characteristics (e.g., the extent to which firms perceive the pharmaceutical firm's other partners as their competitors) that affect the actual transfer of knowledge. Ideally, further research would collect firm-specific data on each of a firm's partner firms. However, we foresee that this may be a challenging undertaking. Many partner firms may not be publicly traded, thereby restricting the available information.

We studied only a firm's portfolio of upstream R&D agreements. Further research might examine a firm's downstream marketing agreements as well and their impact on profitability. We also assumed that all agreements are of similar strength, which may have been a reasonable assumption given our focus on one specific type of cooperation (R&D agreements) but that may be difficult to defend in other empirical settings in which joint ventures and mergers play a more important role.

As for profitability, we do not distinguish between short- and long-term effects on profits. Although we consider this distinction beyond the scope of the current study, future studies might offer the theoretical basis and the appropriate data to disentangle the effects. In addition, our stocks approach to understanding the impact of a firm's innovativeness on profitability can be challenged. This approach somehow conflicts with NPD literature that examines flows of innovations rather than stocks. Future studies that focus on the role of portfolios of interfirm agreements on companies' NPD processes (e.g., the ongoing stream of development projects) would be fruitful.

In addition, we do not provide any information on processes that occur inside the firm. Rather, we control for general proxies such as R&D expenditures, prior innovation experience, and patents. Our theory implies that new drugs result, at least in part, from collaboration efforts. Thus, we do not assess the extent to which new drugs result from purely internal development processes rather than external collaboration. Although internal development processes are affected by resident knowledge, which is in turn gained (at least in part) through collaboration, we do not allow for such an effect explicitly. Further research should focus on the complex relationships between internal development processes and external collaboration.

Finally, by definition, our dependent innovation variables only reflect successful NPD efforts. It may be useful for further research to study the role of agreement portfolios in situations of NPD failure as well. In addition, we believe that our finding that incremental innovations have no significant effect on profitability is somewhat surprising. The role of incremental innovations in conjunction with radical innovations is another interesting issue for further research. It could be argued that firms face a trade-off between radical and incremental innovation that resembles the trade-off between exploration and exploitation discussed in the organizational behavior literature (e.g., March 1991). Garcia, Calantone, and Levine (2003) show that contingent on the level of competition and the profitability of a firm's NPD

activities, the exploitation of existing knowledge bases through refinement and recombination might be more advisable than exploration of new knowledge bases in the short run. Translated to our setting, the generation of incremental innovations that represent refinements of prior successful radical innovations may sometimes be an effective short-term policy. Follow-up studies that address this radical/incremental balance would also benefit from a better discrimination between research activities (exploration) and development activities (exploitation) (Garcia and Calantone

2003; Garcia, Calantone, and Levine 2003), a distinction that was difficult to draw in our empirical setting.

To conclude, although our study is subject to several limitations, we believe that the phenomenon of agreement portfolios and the managerial question of how to organize the portfolios according to the firm's strategic objectives form an important yet understudied research area. Our findings indicate that a portfolio perspective contributes to the understanding of innovation in TI markets.

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