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Benefiting From Alliance Portfolio Diversity: The Role of Past Internal Knowledge Creation Strategy

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The perspective in alliance research has shifted from the individual dyad to alliance portfolios; a key descriptor of a firm's alliance portfolio is diversity. Focusing on firms that are confronted with emerging technological fields, the authors examine the consequences of their alliance portfolio's technological diversity on superior product innovation. The literature has not been conclusive about the consequences of portfolio diversity. The authors examine the nature of the effect of portfolio diversity on superior product innovation and follow up on the call for a contingency perspective—as not all firms benefit equally from portfolio diversity. The contingency perspective is based on the assertion that a firm's past strategies in internal knowledge creation are a source of experiences that increase the firm's capability to leverage extramural knowledge. Theoretically, the study thus contributes to the absorptive capacity literature that has recently acknowledged the importance of such higher-order internal capabilities. By identifying concrete dimensions of internal knowledge creation that enable firms to benefit from portfolio diversity, actionable recommendations are derived on how to align internal knowledge creation with external knowledge sourcing. The empirical support in the biopharmaceutical industry corroborates the developed theory and serves as a warning signal for firms that are ill prepared to leverage a diverse alliance portfolio.

Keywords: *alliance portfolios; diversity; absorptive capacity; knowledge creation; superior product innovation*

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Inspired by theoretical expositions in the strategy literature (Gulati, Nohria, & Zaheer, 2000) and observations of increased formalization of alliance programs in practice (Kale, Dyer, & Singh, 2002; Lavie, 2007), the perspective in alliance research has shifted from the individual dyad to alliance portfolios. Because of aggregate properties not captured by a focus on isolated alliances, alliance portfolio decisions are at the heart of strategic interest (Hoffmann, 2007; Ozcan & Eisenhardt, 2009; Sarkar, Aulakh, & Madhok, 2009; Schilke & Goerzen, 2010; Wassmer, 2010). An alliance portfolio characteristic that has received much attention is diversity (Goerzen & Beamish, 2005; Hoffmann, 2007; Koka & Prescott, 2008). A diverse alliance portfolio provides the firm with access to nonredundant external knowledge bases. The literature has not been conclusive, however, about the consequences of a diverse alliance portfolio (R. T. Jiang, Tao, & Santoro, 2010; Koka & Prescott, 2008; Ozcan & Eisenhardt, 2009). On one hand, a popular viewpoint in the management literature is that in technologically turbulent environments, diversity stimulates firm innovativeness (Baum, Calabrese, & Silverman, 2000; Dutta & Weiss, 1997; Lee, Lee, & Pennings, 2001; Powell, Koput, & Smith-Doerr, 1996). On the other hand, portfolio diversity also has drawbacks such as unwieldy management structures and difficulties in knowledge transfer (Goerzen & Beamish, 2005; Koka & Prescott, 2008).

We examine the consequences of portfolio diversity for superior product innovation. A product innovation is superior when it outperforms the available products in the product category in terms of product advantage for customers (Bonner & Walker, 2004). Superior products are critical to a firm's competitive advantage and growth potential (Drucker, 1985; Langerak, Hultink, & Robben, 2004; Ridley, Grabowski, & Moe, 2006). In the software industry, a focus on technologically superior products that dominate the market distinguishes successful companies in the early stages of high-growth markets (Easingwood, Moxey, & Capleton, 2006). Superior products are scarce, which is one of the reasons why they provide competitive advantage (Ahuja & Lampert, 2001; Jelinek & Schoonhoven, 1990). Developing superior products is further complicated by great uncertainty, especially in technologically turbulent environments where fundamental scientific breakthroughs give rise to new technological fields (Debackere & Rappa, 1994; *Economist*, 2004). The scarcity of superior products in combination with the uncertainties of technological change create resource allocation problems as only few technological trajectories have the potential to lead to superior products and it is very difficult, if not impossible, to identify those trajectories early on. We argue that diversifying the alliance portfolio increases the likelihood of superior product innovation. Mindful of the drawbacks of alliance diversity, we hypothesize (and find) that the effect of portfolio diversity on superior product innovation is nonlinear.

In addition, motivated by the observation that not all firms benefit equally from portfolio diversity, several management scholars have advocated a contingency perspective (e.g., Schilke & Goerzen, 2010; Schilling & Phelps, 2007; Wassmer, 2010). Following up on this call, we examine contingency effects to further address the lack of conclusiveness in the prior literature; we hypothesize that a firm's past strategies to create new knowledge internally moderate the relationship between portfolio diversity and superior product innovation. Our empirical test indicates that the inclusion of contingency effects significantly improves our ability to explain variation in superior product innovation across firms. Our main premise for developing a contingency framework is that internal knowledge creation (Bettis & Prahalad,

1995; Kogut & Zander, 1992; Levinthal & March, 1993) is a source of experience that contributes to the development of a higher-level internal capability to leverage extramural knowledge. Recent advances in the absorptive capacity (AC) literature have pointed to the importance of internal higher-level routines for managing variation and selection (Lewin, Massini, & Peeters, 2011) and the importance of internal invention to build problem-solving routines (King & Lakhani, 2011). We take this line of reasoning one step further and argue that firms that manage to build an internal capability to leverage extramural knowledge are better able to deploy a diverse alliance portfolio for generating superior products. Our findings corroborate this argument.

We thus pursue two main contributions. First, our study contributes to the portfolio literature by examining the main effect of portfolio diversity on superior product innovation and by developing a contingency perspective; second, it contributes to the AC literature by identifying concrete dimensions of internal knowledge creation that enable firms to benefit from external knowledge. These contributions advance the emerging stream of research that explores the link between internal knowledge creation and external knowledge sourcing (e.g., Argote, McEvily, & Reagans, 2003; Cassiman & Veugelers, 2006; Gambardella, 1992; Sampson, 2007; Zaheer & Bell, 2005).

The biopharmaceutical industry provides an appropriate context for an empirical test of the developed theory. Major discoveries in genetic engineering and cell fusion in the 1970s and the subsequent rise of biotechnology represented an important technological discontinuity that threatened the research and development capabilities of incumbent pharmaceutical firms (Henderson & Cockburn, 1994). In their search for superior drugs, pharmaceutical firms accumulated portfolios of alliances with innovative biotechnology firms to gain access to the new technological field (see Vassolo, Anand, & Folta, 2004). Our findings underscore the importance of a contingency perspective to explain why some firms benefited more from portfolio diversity than others. The findings underscore the need for firms in technologically turbulent environments to jointly manage internal knowledge creation and external knowledge sourcing.

Theory and Hypotheses

Below, we first examine the relationship between portfolio diversity and superior product innovation. Then we introduce internal knowledge creation variables and derive contingency hypotheses.

Portfolio Diversity and Superior Product Innovation

Recall that a product innovation is superior when the new product outperforms the available products in the product category in terms of product advantage for customers (Bonner & Walker, 2004). In the pharmaceutical industry, drug superiority (expressed in terms of therapeutic advance for patients) is a dominant driver of prescription behavior (Denig & Haaijer-Ruskamp, 1995; Ellickson, Stern, & Trajtenberg, 1999; Gönül, Carter, Petrova, & Srinivasan, 2001). Superior drugs also have a higher chance of achieving sales of $1 billion or more

within the first five years following FDA approval (Ridley et al., 2006). The inherent scarcity of such superior products and the uncertainty that technologies lead to superior products in emerging technological fields (Macher, 2006) pose important challenges. Resource restrictions preclude even large firms from pursuing many diverse knowledge trajectories in-house (Christensen, 1997; Cooper, 1993; Iansiti, 1998). These resource restrictions motivate firms to forge alliances (Rosenkopf & Almeida, 2003). Novartis, for example, allies with innovative (biotechnology) firms in diverse technology domains to increase the likelihood that at least some of these alliances will result in superior drugs (see activity reports of the Novartis Venture Fund).

As illustrated by the Novartis example, a key alliance portfolio descriptor is the diversity of technological fields that is covered by the different alliances within the alliance portfolio (henceforth referred to as portfolio diversity).[1] With the emergence of nanotechnology, incumbent semiconductor firms similarly engage in technologically diverse R&D alliances with innovative industry partners to keep up with the emerging technological field (L. Jiang, Tan, & Thursby, 2010). Much prior work has underscored the importance of diversifying as a response to uncertainty and risk. Uncertainty and risk motivate CEOs to invest in nonredundant technology domains (May, 1995), banks to diversify geographically (Shiers, 2002), and firms to diversify across business units (Aggarwal & Samwick, 2003; Lubatkin & Rogers, 1989). Also in the innovation literature, much attention has been devoted to diversity, but the literature has not been conclusive as to its consequences for firm innovativeness. Below, we summarize the main arguments.

Access to diverse technology domains has at least three advantages. First, it stimulates breadth of perspective and creative thinking as innovation often results from recombination across diverse technological fields (Fleming, 2001; Goerzen & Beamish, 2005; Hargadon & Sutton, 1997; Henderson & Clark, 1990; Nelson & Winter, 1982; Schumpeter, 1939). Second, exposure to diverse technology domains further increases the likelihood of new external information being associated with knowledge accessed in the past, which facilitates new knowledge assimilation (Cohen & Levinthal, 1990). Third, diversity helps firms cope with the scarcity and uncertainty of superior products. By entering in diverse technology domains, the firm creates the possibility to make a more informed choice later on as uncertainty diminishes (Bowman & Hurry, 1993). Greater diversity of alternatives thus increases the expected value associated with choice (Gavetti & Levinthal, 2000). In layman's terms, betting on different horses increases the chance of winning.

Portfolio diversity also has several drawbacks, however. Firms that develop a diverse portfolio may face problems of information overload and diseconomies of scale (Ahuja & Lampert, 2001). Also, recombination of knowledge becomes excessively difficult when diversity is high (Fleming & Sorenson, 2001). Furthermore, portfolio diversity has been associated with increased difficulty in building strong cohesive ties, transfer of tacit knowledge, and mobilization and coordination of resources (Koka & Prescott, 2008) along with increasingly unwieldy management structures (Goerzen & Beamish, 2005).

It is unclear how the contrasting arguments can be reconciled. Interestingly, prior studies found positive linear effects (Baum et al., 2000; Phelps, 2010; Wuyts, Dutta, & Stremersch, 2004), which seems to suggest that the benefits dominate the drawbacks. We will relax the linearity assumption, however, and explore quadratic effects to allow for the possibility that

the drawbacks of diversity may materialize only when moving from moderate to high diversity; if the latter holds true, we should observe an inverted-U effect.

Hypothesis 1: Portfolio diversity exerts an inverted-U effect on superior product innovation.

Capability to Leverage the Value of Extramural Knowledge

Recently several management scholars have advocated a shift in focus, from a main-effects perspective toward a contingency perspective, to address the question of why some firms benefit more from certain alliance portfolio configurations than others (e.g., Schilling & Phelps, 2007; Wassmer, 2010). Zaheer and Bell (2005), for example, focus on internal capabilities to show that firms differentially benefit from network positions. Building on the literature on AC (e.g., Cohen & Levinthal, 1990, 1994; Lane, Koka, & Pathak, 2006) and higher-order capabilities (e.g., Henderson & Cockburn, 1994; Kogut & Zander, 1992; Nerkar & Roberts, 2004), we examine variation in firm capabilities to explain variation across firms in how they benefit from portfolio diversity.

In particular, we assert that a firm's past internal knowledge creation strategy serves as a source of experience that contributes to the development of a higher-order capability to leverage the value of extramural knowledge. Firms that manage to leverage the value of extramural knowledge are better equipped to benefit from portfolio diversity for generating superior products. This assertion builds on recent advances in the AC literature, where scholars have recently turned their attention to higher-order capabilities. Lewin et al. (2011) examine internal AC capabilities that involve higher-level routines (such as for managing variation and selection). Such routines refer to behavioral regularities that result from cumulative experiences and that constitute the building blocks of capabilities. King and Lakhani (2011) explain how internal invention enables firms to learn about alternative approaches to solving problems, which helps them evaluate external ideas. One problem with the study of such higher-order experiences and routines is their inherent intangibility, which has been a hindrance for empirical inquiry (Lewin et al., 2011). We therefore adopt a more pragmatic approach: Rather than measuring the capability to leverage extramural knowledge directly, we argue that the strategy that firms have used to develop new knowledge internally is a source of experiences that firms can draw on to leverage extramural knowledge. To make the necessary step from theoretical abstraction to actionable recommendations, we identify four key dimensions of internal knowledge creation strategy.

The Moderating Role of Internal Knowledge Creation Strategies

Our selection of the four dimensions of internal knowledge creation is based on four key challenges associated with superior product innovation in technologically turbulent environments. The first three relate to what Ahuja and Lampert (2001: 522) call "organizational pathologies" in the realm of breakthrough inventions: "a tendency to favor the familiar over the unfamiliar; a tendency to prefer the mature over the nascent; and a tendency to search for

solutions that are near to existing solutions rather than search for completely de novo solutions." All of these pathologies can stand in the way of optimally benefiting from diverse alliance portfolios as alliances in technologically turbulent environments cover knowledge domains that are relatively unfamiliar to the firm, cover nascent technological advances, and require de novo solutions. The fourth challenge is intrinsic to diversity: accessing diverse knowledge bases requires a broad outlook on the technological field. We assert that the experiences that firms have accumulated by building an internal knowledge base with (1) low reliance on existing solutions, (2) attention to the unfamiliar, (3) attention to the nascent, and (4) a broad perspective on the technological field help them in leveraging the value of extramural knowledge. As a consequence, we expect these four dimensions of internal knowledge creation to moderate the effect of portfolio diversity on superior product innovation.

To describe firms along these dimensions of internal knowledge creation, we examine the origins of their internal knowledge base. First, divergence from existing industry solutions is captured by (the inverse of) how strongly firms rely on prior industry knowledge for creating new knowledge (Lanjouw & Schankerman, 1999; Mowery, Sampat, & Ziedonis, 2002). Second, attention to the unfamiliar in internal knowledge creation is captured by how much firms rely on knowledge they have previously developed in-house (familiar or proprietary knowledge) versus knowledge that was developed externally by other firms (Sørensen & Stuart, 2000). Third, firms' attention to the nascent is captured by the recency of technological developments they rely on to create new technological knowledge (Nerkar, 2003). Fourth, firms' broad outlook on the technological field is captured by the diversity of knowledge domains they rely on for creating new knowledge (Smith, Collins, & Clark, 2005). In what follows, we develop the corresponding contingency hypotheses.

Prior technological knowledge. A first challenge related to superior product innovation in technologically turbulent environments is that firms need to deviate from previously developed industry knowledge. The organizational learning literature shows that strong embeddedness in preexisting industry knowledge can inhibit deviating from preexisting solutions (Bettis & Prahalad, 1995; Levinthal & March, 1993; Levitt & March, 1988). Firms that rely too much on preexisting industry knowledge are confronted with this restrictive force, reducing their ability to unveil opportunities for new product development (Levinthal & March, 1993). Lanjouw and Schankerman (1999: 11) refer to knowledge that is based more on prior knowledge as derivative innovations, less valuable than knowledge that relies less on prior industry knowledge.

Deploying a diverse alliance portfolio to identify superior product opportunities requires an evaluation of knowledge domains that deviate from established industry knowledge. Firms that embed internal knowledge creation less extensively in prior industry knowledge are more accustomed to deriving solutions that deviate from preexisting industry solutions. These experiences enable them to value extramural knowledge and benefit from portfolio diversity. We hypothesize,

Hypothesis 2: The influence of portfolio diversity on superior product innovation is weakened by reliance on prior industry knowledge in internal knowledge creation.

Firms always rely to some extent on prior industry knowledge. Given their overall reliance on prior industry knowledge, firms differ in terms of the nature of knowledge that they rely on. We elaborate on this below (Hypotheses 3–5).

Proprietary versus external knowledge. Firms often prefer to leverage their own proprietary knowledge rather than external knowledge (Cattani, 2005). The tendency to build further on one's own previous R&D efforts is referred to as "local search" (Helfat, 1994; March & Simon, 1958). The inherent risk of local search is that firms get locked in with familiar paths (Sørensen & Stuart, 2000) and become better and better at competencies that are less and less valued by the environment, resulting in a decrease in fit between competency and environment (Barron, West, & Hannan, 1994; Leonard-Barton, 1992; Levitt & March, 1988).

Following familiar paths is at odds with forging diverse R&D alliances to generate superior products. When a firm has experience with creating new knowledge internally on the basis of external rather than proprietary knowledge, it is better able to evaluate and venture into external knowledge domains. Its experiences with identifying and using externally developed knowledge in internal knowledge creation contribute to the development of a higher-order capability to leverage extramural knowledge. This capability in turn can help firms select the more promising technology domains from a diverse alliance portfolio, enhancing the likelihood of superior product innovation. We expect,

Hypothesis 3: The influence of portfolio diversity on superior product innovation is weakened by reliance on proprietary knowledge in internal knowledge creation.

Old versus recent knowledge. A next challenge posed by pursuing superior product innovation in technologically turbulent industries relates to the notion of creative destruction, that is, the incessant force intrinsic to the evolution of an industry that replaces received wisdom and established approaches by new insights and approaches (Schumpeter, 1939). Technological knowledge development is a cumulative and progressive process with more recent knowledge on average being superior to older knowledge (e.g., Clarysse, Debackere, & Rappa, 1996). Similarly, Sørensen and Stuart (2000: 93) explain that "firms that cite new patents are elaborating on the most contemporary areas of technology." Consistent with this view, reliance on more recent knowledge for internal knowledge creation will more likely lead to advances in new product development (Nerkar, 2003). As superior products represent substantial advances over competing products, knowledge recency is particularly important in this context.

In technologically turbulent environments, R&D alliances are formed with firms that do cutting-edge research (Narula, 2004; Pisano, 1990). The recency of knowledge accessed through alliances requires that for firms to optimally benefit from alliance activity, they should be experienced in dealing with nascent knowledge domains and equipped to track the latest technological developments. Firms with a history of creating new knowledge internally on the basis of recent rather than old knowledge have accumulated experiences with screening the environment for recent developments. These experiences facilitate the task of

tracking external alliance opportunities and assessing their potential in terms of superior new products.

Hypothesis 4: The influence of portfolio diversity on superior product innovation is strengthened by reliance on more recent knowledge in internal knowledge creation.

Diverse knowledge. Finally, superior product innovation often requires insight into diverse knowledge domains to achieve a better match with customer requirements (Clark & Fujimoto, 1991; Iansiti, 1998). Sourcing from diverse knowledge domains provides opportunities for experimentation and recombination and enables firms to circumvent limitations of bounded rationality and local search (Cohen & Levinthal, 1990; March & Simon, 1958). Firms that create internal knowledge on the basis of diverse knowledge domains thus have a higher likelihood of generating innovations that are more valuable (Smith et al., 2005; see also Henderson & Clark, 1990, for examples in the photolithographic alignment equipment industry).

Prior experiences with integrating diverse knowledge domains to create new knowledge internally contribute to the capability of leveraging extramural knowledge. The experiences and routines that result from diverse sourcing may prove useful when confronted with diverse external alternatives. Firms that have accumulated internal experiences with knowledge integration are better positioned to identify and evaluate external knowledge domains; we hypothesize,

Hypothesis 5: The influence of portfolio diversity on superior product innovation is strengthened by reliance on diverse knowledge in internal knowledge creation.

Method

The pharmaceutical industry is a particularly suitable empirical context for testing the hypotheses. It is a prototypical example of a technologically turbulent industry in which innovation occupies a central position. In particular, the 1980s marked the emergence of the new technological field of biotechnology (following scientific breakthroughs of genetic engineering and cell fusion), and pharmaceutical firms accessed the emerging technological field through alliances with biotechnology firms (Grant & Baden-Fuller, 2004). As a result, throughout the 1990s pharmaceutical firms relied as much on external knowledge search as on internal knowledge development (Pisano, 1990; Powell et al., 1996), which poses specific challenges for generating superior drugs. Firms such as GlaxoSmithKline and Eli Lilly considered their alliances with upstream partners as indispensable and complementary with the development of their internal capabilities. Merck developed a diverse alliance portfolio with the explicit objective to increase the likelihood of successful drug generation (Remer, Ang, & Baden-Fuller, 2001). An additional advantage of the setting of the pharmaceutical industry and the rise of biotechnology is data availability. Thanks to intensive patenting activity in this industry, objective information on internal knowledge creation is available; industry databases contain information on interfirm cooperation in R&D as well as on the technological subdomains that underlie all individual alliances; and the FDA distinguishes superior drugs from standard drugs on the basis of very extensive trials.

While our theoretical focus is on the linkage between portfolio diversity and superior drug generation and how this linkage is contingent on past internal knowledge creation strategies, we also examine the direct effects that internal knowledge creation strategies may exert on the generation of superior drugs. Below, we describe data sources, measures, and estimation procedure, and we report estimation results.

Data Sources and Measures

The core variables of our conceptual framework were collected by combining diverse data sources: Recombinant Capital (Recap), U.S. Patent and Trademark Office (USPTO) and National Bureau of Economic Research (NBER), and FDA Drug Approvals. Below we discuss data and measures in detail.

Recap. The Recap database contains information on alliances in the biopharmaceutical industry. Our focus is on R&D alliances formed by pharmaceutical firms with dedicated biotechnology firms, as such upstream alliances were the vehicles for pharmaceutical firms to access drastically different competencies that were found in dedicated biotechnology firms (Rothaermel, 2001; Rothaermel & Boeker, 2008). For each agreement between a pharmaceutical firm and a biotechnology firm, the database provides information not only on the identity of the partners but also on the underlying technology domain (categorized by biotechnology experts). The latter allows us to calculate a measure of technology diversity in the firm's alliance portfolio, up to a given year. We consider the period 1985–1999. The year 1985 is a natural starting point as it is halfway in the 1980s, when biotechnology started to emerge as a new technological field in the pharmaceutical industry and 1985 marks the beginning of pharmaceutical firms' response to this evolution by forging R&D alliances with dedicated biotechnology firms (e.g., Hoang & Rothaermel, 2005; Wuyts et al., 2004). We chose 1999 as the end date, as by the end of the 1990s pharmaceutical companies had established significant capabilities of their own in the new field (see Vassolo et al., 2004: 1050). Consistent with prior literature (Powell et al., 1996), we measure the degree of technological diversity in firm i's portfolio of R&D alliances with biotechnology firms (PORTF_DIV) as one minus the sum of squared proportions of each technology domain's occurrence in the alliance portfolio,

$$PORTF\_DIV_i = 1 - \sum_{j=1}^{N} p_{ij}^2$$

where N = total number of different technology domains covered by firm i's alliance portfolio and

$$p_{ij} = \frac{\text{number of firm } i\text{'s alliances in technology domain } j}{\text{total \# alliances in firm } i\text{'s alliance portfolio}}$$

To make sure that we incorporate all potentially relevant agreements that can affect the generation of new products at time t and acknowledging that such agreements can be signed

at different stages in the development process, we consider the firm's entire alliance portfolio (starting in 1985, the inception of alliance activity in the industry) up to year *t*-1. We use a 20% depreciation rate of technological knowledge (consistent with Henderson & Cockburn's, 1994, approach in the same industry). We report on the sensitivity of the findings to our choice of a 20% depreciation rate in the robustness section.

USPTO/NBER. The USPTO and NBER databases contain patent data that provide insight into a firm's internal knowledge creation strategy (e.g., DeCarolis & Deeds, 1999). Patents are the "earliest" available records of internal knowledge available for research. Yet they are an outcome of the knowledge creation process; our primary interest is in how internal knowledge has been created. We gathered such information by examining the list of patents cited in each of a firm's patents (i.e., patents the firm has relied on to generate a new patent). Patent citations appear at the back of each patent. While the patentee obviously has the incentive to cite as few other patents as possible in a patent application, a patent examiner verifies the correctness of patents cited and eventually demands that other patents are cited before granting (Lanjouw & Schankerman, 1999). This important role of the patent examiner enhances the validity of these measures. Not all patents translate into new products: Patent data represent large portions of both failed and successful inventions (Fleming, 2001). This is in line with our theorizing as experience results from both successes and failures. For successful inventions, it takes on average 10 years to translate a patent into an approved drug (Nichols, 1994; confirmed in our own interviews with practitioners). Accounting for some variation around 10 years, we consider the patents in the time window [*t*-12, *t*-8] to influence the generation of superior drugs at time *t*. We used this time window [*t*-12, *t*-8] to measure the different internal knowledge creation variables described next. In the robustness section, we report on the robustness of the results when using alternative time windows. Importantly, the use of an 8- to 12-year lag is required to capture not only the firm's experience with creating knowledge but also its experiences with (either successfully or unsuccessfully) translating internally created knowledge into new products.

Reliance on prior technological industry knowledge. We measure reliance on prior technological industry knowledge (PRIOR_KNOW) as the average number of patents cited in firm *i*'s own patents applied for in years [*t*-12, *t*-8]. 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. The number of patents cited thus reflects the extent to which the patent relies on preexisting knowledge, that is, "uses existing ideas" (Caballero & Jaffe, 1993) or relies on "prior art" (Mowery et al., 2002). Hall, Jaffe, and Trajtenberg (2001) validate this measure and show that patents that cite more other patents, that is, rely more on prior industry knowledge, belong to less novel knowledge domains.

Reliance on proprietary knowledge. For a measure of reliance on a firm's proprietary knowledge (PROP_KNOW), we use the average proportion of self-citations in a firm's patents applied for in years [*t*-12, *t*-8] (i.e., the proportion of the firm's own prior patents in all patents cited, Rosenkopf & Nerkar, 2001). This index is also referred to as leverage of a firm's stock of skills and knowledge (Cattani, 2005).

Reliance on recent knowledge. We measure the inverse of knowledge recency, namely, knowledge age (AGE_KNOW), by examining the average age of the patents cited in a firm's patents applied for in years [*t*-12, *t*-8]. As age is an inverse index of knowledge recency, a negative interaction effect between age and portfolio diversity would support Hypothesis 3.

Reliance on diverse knowledge. Reliance on diverse knowledge domains (DIV_KNOW) is measured as the diversity of technology domains cited in firm *i*'s patents, applied for in years [*t*-12, *t*-8]. If a firm creates new knowledge by relying on patents from diverse technology domains, the corresponding score will be high (Hall et al., 2001). The measure for knowledge diversity for a given patent *i* is consistent with the portfolio diversity measure, that is, one minus the Herfindahl index,

$$KNOWLEDGE\_DIVERSITY_{patent\ i} = 1 - \sum_{j=1}^{ni} s_{ij}^2,$$

where n_i = total number of patent classes cited in patent *i* and

$s_{ij} = \dfrac{\text{number of citations by patent } i \text{ that belong to patent class } j}{\text{total \# citations by patent } i}$. The measure for a firm's reliance on diverse knowledge is the average diversity of its patents in [*t*-12, *t*-8].

FDA drug approval list. We measure superior product advantage for a new drug by its therapeutic advance for patients as compared to available therapy in the therapeutic category. The FDA distinguishes between standard drugs that have "therapeutic qualities similar to those of an already marketed drug" and drugs that represent "an advance over available therapy." For a drug to be classified as an advance over available therapy, that is, a superior drug, improvement over available drugs has to be demonstrated in one of four ways (Center for Drug Evaluation and Research, 1996): evidence of increased effectiveness in treatment, prevention, or diagnosis of a disease; elimination or substantial reduction of a treatment-limiting drug reaction; documented enhanced patient compliance; or evidence of safety and effectiveness in a new subpopulation. An example is Parke-Davis's (and later Pfizer's) cholesterol drug Lipitor, the only drug in its class that lowered both elevated LDL ("bad") cholesterol and triglycerides (biochemical compounds that increase in concentration when consuming fats) in the bloodstream. The FDA's expert qualification of new drugs as superior drugs is an informed decision as it is based on intensive consecutive test phases, which progressively reduce uncertainty regarding a drug's superiority (Danzon, Nicholson, & Pereira, 2003; *Economist*, 2004; Nichols, 1994). The FDA's Center for Drug Evaluation and Research seeks regular advice from advisory committees consisting of physicians and other experts, the drug evaluations are based on detailed reports from clinical trials with patients, and the FDA also collects inputs from patient groups directly through a series of regular meetings. Finally, therapeutic advance has been validated as a useful indicator of superiority in that drugs that are classified by the FDA as providing superior therapeutic advance effectively lead to higher patient benefits (e.g., in terms of longevity, see Lichtenberg, 2002).

In the application context of the pharmaceutical industry, we observe that most variation in the data in terms of superior product innovation is variation between 0 and 1, which underscores the scarcity that is intrinsic to superior products. Only in a few occasions are pharmaceutical firms able to generate two superior drugs in a given year. Hence, we opt for a binary dependent variable SUP_{it} (where observed values of 1 and 2 are set to 1). This approach is consistent with the developed theory, which relates to a firm's ability for superior product innovation. We will examine the robustness of the findings when using count models.

Control Variables

Main effects internal knowledge creation variables. Obviously, the main effects of the internal knowledge creation variables are included in the model specification. The ability of firms to develop superior products may also directly depend on the strategies they have adopted to create technological knowledge internally (Glazer, 1991; Jelinek & Schoonhoven, 1990).

Firm size. We control for firm size (FIRM_SIZE), lagged one period, by specifying the log of the number of employees (sourced from Compustat), accounting for the resource allocation advantages of large firms but also for the restrictive effects of inertia (Cohen & Levin, 1989). In the robustness section, we examine alternative operationalizations.

R&D expenditures. We control for the allocation of the firm's resources to R&D activities (R&D_EXP), lagged one period, to account for the likely positive influence of R&D expenditures on the generation of superior drugs. Exploratory analyses revealed that the effect of R&D expenditures is curvilinear, so we also include a quadratic term.

Size of a firm's internal knowledge base. The size of a firm's internal knowledge base is operationalized as the firm's total number of patents (PATENTS) applied for in [*t*-12, *t*-8], weighted with the number of citations that each of these patents have received, as is common practice in the literature (e.g., Trajtenberg, 1990). This control variable suffers from right-censoring because for a recent patent, we observe only a fraction of all citations. To address this problem we follow the approach suggested by Trajtenberg (1990) and weigh the number of patent citations by the time span from application to the current year under consideration.

Portfolio size. We also control for the total number of R&D agreements (using a 20% depreciation rate) up to year *t*-1 (PORTF_SIZE), which reflects the firm's overall exposure to external biotechnology knowledge.

Time trend and year effects. Finally, we specify a time trend in view of some observations in the popular press that pharmaceutical firms have faced increasing difficulty to generate superior drugs. We also include year dummy variables to account for differences in drug generation across years.

Sample and Estimation Approach

We collected these data for 52 large pharmaceutical firms. The final data set consists of 432 observations, that is, on average 8 yearly observations per firm. We compose a data set starting with the inception of alliance activity in the biopharmaceutical industry (in 1985), which marks the start of the emergence of biotechnology as a scientific field with commercial potential. As mentioned earlier, 1999 is a natural end point because at the end of the 1990s biotechnology has turned into an established field with pharmaceutical firms having developed strong internal biotechnology capabilities (Vassolo et al., 2004). In the period [1985, 1999] the 52 firms collectively engaged in 687 R&D alliances with dedicated biotechnology firms. Our focus on large firms coincides with the phenomenon under study, with large established firms forming portfolios of alliances in the face of an emerging technological field.

Table 1 contains basic descriptors and a correlation matrix (note that the variables involved in quadratics or interactions are mean-centered). The unit of analysis is the pharmaceutical firm *i* in year *t*; the dependent variable is superior product innovation by firm *i* in year *t*. Since we operationalized superior product innovation as a binary variable, we estimate a probit model. In view of the panel structure of our data set with multiple observations per firm, we conducted likelihood ratio tests to test if a random effects specification is required. However, the improvement in model fit is not significant when specifying random effects. Hence, we report the most parsimonious model, that is, without random effects specification. All models reported below, however, are robust for the specification of random effects. We also estimated count models to account for the difference between values of 1 and 2 in the dependent variable. The estimation of Poisson and negative binomial regression models resulted in similar results. In addition, we estimated a logit model as an alternative binary model. The reported results are robust to all these alternative specifications, which enhances our confidence in the results and shows that the results are not sensitive to distributional assumptions. We tested for potential multicollinearity and found all variance inflation factors to be within acceptable limits (i.e., below 10, the threshold that indicates harmful collinearity; Mason & Perreault, 1991). The average variance inflation factor was 2.88.

Results

Model comparison. Table 2 presents the marginal effects for three nested probit models. Model 1 is the full model that includes all four internal knowledge creation variables (both main and interaction effects); Model 2 excludes two internal knowledge creation variables (main and interaction terms), namely, reliance on proprietary knowledge and knowledge recency, because Model 1 shows insignificant main and interaction effects for these two variables; Model 3 excludes also the other two internal knowledge creation variables, namely, reliance on prior industry knowledge and knowledge diversity. When comparing the log likelihoods of the full Model 1 (LL = –85.35) and Model 2 (LL = –89.23), we conclude that the inclusion of proprietary knowledge and knowledge recency does not significantly

Table 1
Correlation Matrix

	M	*SD*	Range	1	2	3	4	5	6	7	8	9	10
1. SUP(0/1)	0.10	0.30	1	1									
2. Portfolio diversity (PORTF_DIV)	0	0.38	0.93	.30	1								
3. Proprietary knowledge (PROP_KNOW)	0	0.16	0.68	.20	.36	1							
4. Age knowledge (AGE_KNOW)	0	4.39	24.72	.07	.14	.19	1						
5. Prior knowledge (PRIOR_KNOW)	0	4.68	26.00	–.06	.06	.16	.55	1					
6. Diverse knowledge (DIV_KNOW)	0	0.18	0.79	.07	.16	.28	.63	.69	1				
7. R&D expenditures (R&D_EXP)	0	0.88	4.53	.37	.46	.43	.03	–.12	.05	1			
8. # citation-weighted patents (PATENTS)	664.71	954.34	5,643	.26	.43	.64	.12	.16	.20	.51	1		
9. Portfolio size (PORTF_SIZE)	7.48	10.99	62	.32	.64	.35	.09	–.00	.07	.62	.47	1	
10. Firm size, logged (FIRM_SIZE)	0.88	0.73	4.01	.24	.45	.42	.28	.04	.29	.64	.44	.49	1

improve model fit at 5% significance level (minus two times the difference in log likelihood is chi-square distributed with four degrees of freedom). The main effects of reliance on proprietary knowledge ($\beta = -.01$, $p = .81$) and knowledge recency ($\beta = .00$, $p = .55$) are insignificant; their interactions with portfolio diversity have the hypothesized signs but are significant only at the 10% significance level when using a one-sided test (resp. $\beta = -.19$, $p = .12$; $\beta = -.01$, $p = .16$ where the p-values are based on two-sided tests). Since the addition of these main and interaction effects does not improve model fit, we reject Hypotheses 3 and 4.

When moving from Model 2 (LL = –89.23) to Model 3 (LL = -97.59), however, we do observe a significant deterioration in model fit at 1% level. Thus, reliance on prior industry knowledge and knowledge diversity and their respective interactions with portfolio diversity

Table 2
Probit Estimation Results Superior Drugs Equation

	Model 1	Model 2	Model 3
	Full Model, Marginal Effect (*SE*)	Model 1, Excluding Main and Interaction Effects of PROP_KNOW and AGE_KNOW	Model 2, Excluding Main and Interaction Effects of PRIOR_KNOW and DIV_KNOW
Portfolio diversity (PORTF_DIV)	.07 (.04)*	.09 (.04)*	.13 (.04)**
$(PORTF\_DIV)^2$	.36 (.19)**	.51 (.18)**	.58 (.00)**
Prior knowledge (PRIOR_KNOW)	–.01 (.00)*	–.01 (.00)*	—
Proprietary knowledge (PROP_KNOW)	–.01 (.06)	—	—
Age knowledge (AGE_KNOW)	.00 (.00)	—	—
Diverse knowledge (DIV_KNOW)	.23 (.10)**	.30 (.10)**	—
PORTF_DIV × PRIOR_KNOW	–.02 (.01)*	–.02 (.01)*	—
PORTF_DIV × PROP_KNOW	–.19 (.12)	—	—
PORTF_DIV × AGE_KNOW	–.01 (.01)	—	—
PORTF_DIV × DIV_KNOW	.43 (.26)*	.46 (.24)*	—
R&D expenditures	.04 (.02)**	.05 (.02)*	.07 (.03)**
$(R\&D\ expenditures)^2$	–.01 (.00)*	–.01 (.00)*	–.02 (.01)†
Citation-weighted patents	.00 (.00)	.00 (.00)	.00 (.00)
Portfolio size	–.00 (.00)	–.00 (.00)	–.00 (.00)
Firm size	–.02 (.02)	–.03 (.02)	–.02 (.02)
Time trend	–.00 (.00)	–.00 (.00)	–.00 (.00)
1996 dummy	.68 (.30)*	.07 (.04)*	.09 (.05)*
Log likelihood	–85.35	–89.23	–97.59

†$p < .10$. *$p < .05$. **$p < .01$. All significance tests are two-sided.

explain significant variation in superior product innovation. On the basis of the model comparisons, we use Model 2 to test Hypotheses 1, 2, and 5.

First, let us consider the quadratic effect of portfolio diversity. Since we mean-centered the explanatory variables, a negative effect for the quadratic term would be supportive of the hypothesized inverted-U effect. However, both the main term and the quadratic term are positive and significant (main effect: $\beta = .09$, $p < .05$; quadratic term: $\beta = .51$, $p < .01$), indicating a U-shaped effect of portfolio diversity on superior product innovation. We will discuss this unexpected finding in the discussion section.

Second, we turn to the test of contingency hypotheses, Hypotheses 2 and 5. We find support for Hypothesis 2, as reliance on prior industry knowledge weakens the effect of portfolio diversity on superior product innovation ($\beta = -.02$, $p < .05$). Also, the main effect of reliance on prior industry knowledge is negative and significant ($\beta = -.01$, $p < .05$). We also find support for Hypothesis 5, as reliance on diverse knowledge enhances the effect of portfolio diversity on superior product innovation ($\beta = .46$, $p < .05$). Reliance on diverse knowledge also exerts a significant main effect on superior product innovation ($\beta = .30$, $p < .01$).

Third, in the specification of Model 2, two of the control variables are significant. The effect of R&D expenditures is curvilinear in nature (main term: $\beta = .05$, $p < .05$; quadratic term: $\beta = -.01$, $p < .05$, indicating an inverted-U effect). Furthermore, one year dummy variable (for the year 1996) was retained; the effects of all the other year dummy variables were insignificant.

Robustness tests. First, we made assumptions regarding the time lags for the independent variables. In particular, prior studies on the lead time from patent application to drug approval as well as our own communications with experts in the pharmaceutical industry suggest that patents applied for in the time window [*t*-12, *t*-8] can influence the generation of new drugs at time *t*. We verified the robustness of the results for reasonable deviations, such as [*t*-15, *t*-10] and found our results to be robust for such deviations. Furthermore, we used a one-year time lag for the portfolio variables (size and diversity), acknowledging that alliances with biotechnology partners are signed at different development stages. We examined the sensitivity of the reported results to alternative time lags, including two- and three-year lags, and found that the reported results are not sensitive to these changes in time lags. Second, the results are robust when using different levels of the knowledge depreciation rate (ranging from 10% to 30%). Third, the results do not change when using alternative proxies for the firm size variable, such as firm assets. Fourth, in view of previous research studies, we also explored the possibility of curvilinear effects for the four internal knowledge creation variables, but the specification of quadratic terms did not improve model fit (the resulting models were all inferior to Model 2) and did not lead to any additional insights. In summary, the results are robust, that is, not determined by any particular assumption made in the specification of the model.

Discussion

The combined results corroborate that a diverse alliance portfolio is a valuable asset for innovative firms. However, the findings sketch a more nuanced picture. First, the positive main and quadratic effects of portfolio diversity provide evidence of a U-shaped effect (as portfolio diversity is mean-centered, a positive and significant quadratic effect on its own would have indicated a symmetric U shape; as we find that also the main effect is positive and significant, the U shape is skewed toward a positive effect). This unexpected finding indicates that while the highest levels of portfolio diversity are associated with the highest likelihood of generating superior products, very low diversity also has some merit; this seems to suggest that also a focus strategy in external knowledge sourcing can contribute to the generation of superior products—albeit not as strongly as a diversity strategy. For a more comprehensive understanding of the direct effect of portfolio diversity, more research is required, preferably with alternative dependent variables that also account for the costs of diversity and with possible mediating variables to identify the exact mechanisms at work. Second, in response to recent calls to examine contingency effects, we show empirically that not all firms are equally equipped to benefit from portfolio diversity in terms of generating superior products. Portfolio diversity increases the likelihood of superior product innovation more for firms that embed *internal* knowledge creation less in prior industry knowledge and that rely more on diverse knowledge. These findings give credence to our assertion that past internal knowledge creation is a source of experiences that contribute to a firm's ability to manage portfolio diversity and leverage extramural knowledge.

The contingency approach developed in this study contributes to both the AC and the alliance portfolio literatures. In the AC literature, the relevance of higher-order routines and capabilities has recently been acknowledged (King & Lakhani, 2011; Lewin et al., 2011). By

singling out specific internal knowledge creation strategies, we can formulate concrete recommendations regarding internal AC-related routines. In particular, firms are better able to identify the scarce superior product opportunities in their diverse alliance portfolio if they manage to deviate from prior art and if they maintain a broad outlook on the technological field in their internal knowledge creation efforts. As to the portfolio literature, the significant improvement in model fit corroborates that a portfolio perspective is enriched by inclusion of firm-level differences. While the need to account for firm differences is intuitively appealing and acknowledged by some (e.g., Schilke & Goerzen, 2010; Schilling & Phelps, 2007; Wassmer, 2010), most portfolio as well as network studies make abstraction of the identity of actors and thus implicitly assume differences between actors to be irrelevant to the understanding of network benefits. Our empirical test identifies internal knowledge creation strategies that enable firms to benefit more from their external knowledge sourcing strategies. The findings clearly show that firms should not delegate exploratory search to their alliance activities while maintaining a strong focus internally. On the contrary, they should become accustomed with deviating from established paths and with technological recombination and integration in their internal knowledge creation activities to benefit from their diverse alliance activities. This insight is consistent with anecdotal evidence in the pharmaceutical industry: Merck Research Laboratories attributed its success in effective commercialization of knowledge sourced from biotechnology firms (with one third of its products stemming from external research in 2000) to its internal innovative strategy (Pisano, 2002).

In addition to their moderating role, two internal knowledge creation strategies also directly help generate superior products. Creating new knowledge by deviating from preexisting industry solutions and by sourcing from diverse knowledge domains contributes to superior product innovation, in line with the prior literature. From the combined findings, we conclude that (1) both external knowledge sourcing and internal knowledge creation strategies are alternative direct routes to superior product innovation and (2) they should be managed jointly since the experiences gained through internal knowledge creation help firms benefit from the opportunities of portfolio diversity. Put differently, external knowledge sourcing should not *substitute* for internal knowledge creation: rather, they are complements.

Limitations and Future Research

Our empirical test is restricted to the pharmaceutical industry, which limits its generalizability. The rise of biotechnology and the associated tendency to ally with biotechnology firms, however, extend to other industries including chemicals, agriculture, food processing, environmental mining, energy, cosmetics, and IT (Enriquez & Goldberg, 2000). Furthermore, the developed theory is not context specific but likely applicable to other industries characterized by emerging technological fields.

Also, our sole focus on products that have successfully traveled the long path toward FDA approval is restrictive. We had no data on failed products, even though such information would be useful for further understanding the drivers of superior product innovation. Furthermore, our data did not provide insight into more intricate dynamics over time. There may be a dynamic iterative process between internal knowledge development and external knowledge sourcing, as external knowledge may be internalized at some point in time and

subsequently aid in internal knowledge creation. Unfortunately, a study of such iterative processes requires data over a very extensive period, particularly in an industry where the lag between internal knowledge creation and a finalized product is very long. The FDA has not consistently recorded information on drug superiority for such an extended period. Perhaps an elaborate study of the (presumably) iterative character of internal knowledge creation and alliance activity is more feasible in other industries where the lag between internal knowledge creation and a finalized product is shorter.

Our use of secondary data also precluded a direct measurement of the second-order capability to leverage extramural knowledge. Even though the findings are in line with our theorizing, they do not offer any direct evidence that past knowledge creation strategies effectively serve as sources of experience that contribute to the development of such a capability. Comparative case studies or extensive survey research (e.g., see Schilke & Goerzen, 2010) would be invaluable to address this limitation. More generally, we have no insight into the intervening factors that may be at play in the 10-year period where patents are translated into new drugs. Recall that our random effects specification did not pick up any systematic differences across firms that may bias the results, suggesting that unobserved heterogeneity may not be of much concern. Nevertheless, rather than correcting econometrically for unobserved heterogeneity, scholars may employ a longitudinal case study approach to identify potential intervening factors.

Finally, a longitudinal case study approach, as suggested above, would also allow for a different unit of analysis, namely, the project rather than the firm. Complementary insights can be obtained by studying internal knowledge development and external knowledge sourcing at the project level. A detailed consideration of the internal and external inputs that enter an R&D project and the lengthy process to the (un)successful generation of a superior product would provide insights that complement our approach.

Note

1. Diversity is equivalent to the concept of nonredundancy in the network literature. Initially introduced as a correlate of weak ties, a result of unexpected research findings (Granovetter, 1973), nonredundancy has turned into a core concept in structural holes theory (Burt, 1992) as well as bridging theory (DiMaggio, 1992; McEvily & Zaheer, 1999).

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