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EXPLORATION AND EXPLOITATION ALLIANCES IN BIOTECHNOLOGY: A SYSTEM OF NEW PRODUCT DEVELOPMENT

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We link the exploration–exploitation framework of organizational learning to a technology venture's strategic alliances and argue that the causal relationship between the venture's alliances and its new product development depends on the type of the alliance. In particular, we propose a product development path beginning with exploration alliances predicting products in development, which in turn predict exploitation alliances, and that concludes with exploitation alliances leading to products on the market. Moreover, we argue that this integrated product development path is moderated negatively by firm size. As a technology venture grows, it tends to withdraw from this product development path to discover, develop, and commercialize promising projects through vertical integration. We test our model on a sample of 325 biotechnology firms that entered 2565 alliances over a 25-year period. We find broad support for the hypothesized product development system and the moderating effect of firm size. Copyright © 2004 John Wiley & Sons, Ltd.

Strategic alliances are a ubiquitous phenomenon, especially in high-technology industries (Hagedoorn, 1993). Parallel to the rise in interfirm cooperation, research on strategic alliances has burgeoned, with one strand focusing on the performance impact of alliances on the focal firm (Gulati, 1998). In this line of inquiry, several scholars have studied the relationship between a firm's strategic alliances and its innovative performance or new product development (Shan, Walker, and Kogut, 1994; Kotabe and Swan, 1995; Deeds and Hill, 1996; Baum, Calabrese, and Silverman, 2000; Lerner, Shane, and Tsai, 2003). This is an important avenue of research since a firm's innovativeness and new product development have a direct impact on its continued survival and performance, particularly in high-technology industries (Brown and Eisenhardt, 1997).

Prior research provided evidence for the notion that a firm's strategic alliances have a positive impact upon its innovativeness (Shan *et al*., 1994), and that the relationship between alliances and new product development might be characterized by diminishing marginal returns (Deeds and Hill, 1996). Others have shown that a start-up's configuration of alliances impacts its early performance (Baum *et al*., 2000), and the nature of a firm's cooperative arrangements has a bearing on the firm's level of product innovativeness (Kotabe and Swan, 1995). More recently, Lerner *et al*. (2003) found that strategic alliances entered between small technology ventures and large established firms during periods of limited external equity financing tended to be less successful.

While each of these studies has certainly advanced our understanding of the new product

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development process by establishing a link between a firm's strategic alliances and an intermediate research output or performance indicator, such as patenting propensity (Shan *et al*., 1994; Baum *et al*., 2000), level of product innovativeness (Kotabe and Swan, 1995), products under development (Deeds and Hill, 1996), and milestone stages reached (Lerner *et al*., 2003), linking different types of alliances to each distinct stage in the new product development process beginning with discovery and culminating in commercialization has not yet been undertaken. Understanding more fully the role of firm allying along the entire new product development process seems particularly salient when considering that most innovations will either never reach the market (Griffin, 1997; Stevens and Burley, 1997), or if they do, they are not likely to meet financial expectations (Booz-Allen & Hamilton, 1982).

Herein, we build on the exploration–exploitation model of organizational learning (March, 1991). Koza and Lewin subsequently applied this model to a firm's strategic alliances and argued that a firm's decision to enter an alliance 'can be distinguished in terms of its motivation to exploit an existing capability or to explore for new opportunities' (Koza and Lewin, 1998: 256). In the early stages of a development project, a technology venture undertakes exploratory search in the attempt to discover something new. This search is frequently structured through exploration alliances (Rosenkopf and Nerkar, 2001). Following successful exploration, the venture's search process turns to exploiting this new knowledge, often in conjunction with a partner firm through exploitation alliances (Rothaermel, 2001a). We propose an integrated product development path where a technology venture's exploration alliances predict its products in development, while a venture's products in development predict its exploitation alliances, and where its exploitation alliances in turn lead to products on the market (Figure 1).

Given the fact that high-technology start-ups generally face resource constraints, it is likely that these ventures rely on alliances with established firms for access to capital (Majewski, 1998), in particular in tight equity markets (Lerner *et al*., 2003), and for access to product markets (Hill and Rothaermel, 2003). Due to their initially weak bargaining position, new technology ventures tend to cede a disproportional amount of control rights to the financier of the R&D alliance (Aghion and Tirole, 1994; Lerner and Merges, 1998). Hence, we also hypothesize that internal resources are substituted for external alliances as a technology venture grows, implying that firm size negatively moderates the product development path leading from exploration alliances to products on the market. We empirically test this system of new product development and the suggested moderating effect of firm size on a sample of 325 biotechnology

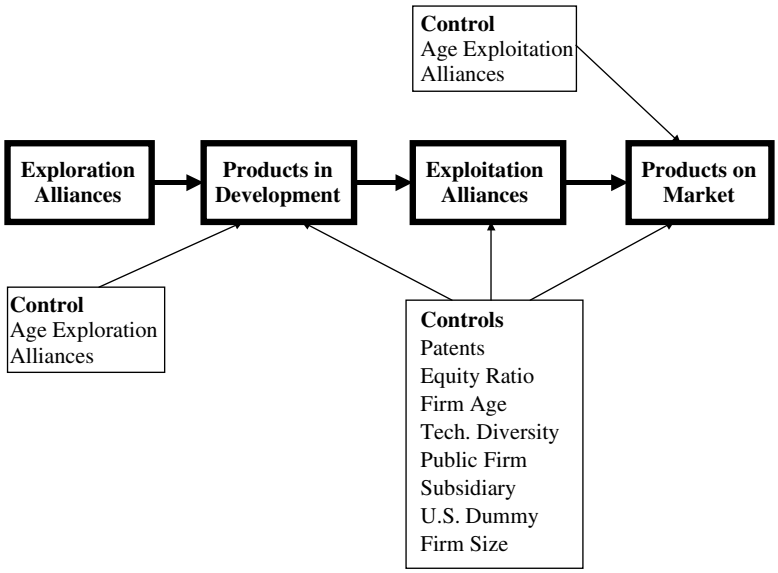

Figure 1. Firm allying and new product development

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firms that entered into 2565 alliances in the 25-year period between 1973 and 1997.[1]

EXPLORATION, EXPLOITATION, AND NEW PRODUCT DEVELOPMENT: THEORY AND HYPOTHESES

Prior research has argued that learning alliances allow firms to increase the speed of capability development and minimize uncertainty by acquiring and exploiting knowledge developed by others (Grant and Baden-Fuller, 1995; Lane and Lubatkin, 1998; Dussauge, Garrette, and Mitchell, 2000). From the generation of new ideas through the launch of a new product, the creation and exploitation of knowledge is a core theme of the new product development process. In fact, the entire new product development process can be viewed as a process of embodying new knowledge in a product (Madhavan and Grover, 1998). To more fully understand the relationship between firm allying and R&D outcomes, it is prudent, however, to consider the type of learning imbued into the project during the various stages of the product development process. Different stages of the product development process motivate different types of searches and thus entry into different types of alliances for firms collaborating in the market for know-how.

We employ March's (1991) exploration–exploitation framework to characterize the type of search and the type of alliances firms are pursuing at different stages of the product development process. A firm's choice of the type of alliance to enter can be distinguished by its motivation to either explore for new opportunities or exploit an existing opportunity (Koza and Lewin, 1998). Exploration generates discovery of new opportunities and, at the same time, the potential for exploitation. Thus, successful exploration also creates demand for resources required to exploit newly discovered opportunities. In the spirit of an evolutionary perspective, we argue that exploitation alliances are dependent on the firm's prior exploration activities. Specifically, we propose a product development system in which an R&D organization's exploratory alliances motivate subsequent exploitative alliances. Further, we propose that new technology ventures that use exploration and exploitation alliances to organize for innovation tend to commercialize more products.

The exploration–exploitation framework developed by March (1991) and refined by Levinthal and March (1993) provides a framework for understanding the needs of technology ventures at different stages of the product development process. March (1991) described exploration as 'experimentation with new alternatives' having returns that 'are uncertain, distant, and often negative' and exploitation as 'the refinement and extension of existing competencies, technologies, and paradigms' exhibiting returns that 'are positive, proximate, and predictable.' March thus concluded that 'the distance in time and space between the locus of learning and the locus for realization of returns is generally greater in the case of exploration than in the case of exploitation, as is the uncertainty' (March, 1991: 85). Later, Levinthal and March (1993: 105) defined exploration as 'the pursuit of knowledge, of things that might come to be known,' and exploitation as 'the use and development of things already known.'

An important distinction between exploration and exploitation processes can be based on their precursors. The precursor to exploration is simply desire, the wish to discover something new. The precursor to exploitation, however, is the existence of an exploitable set of resources, assets, or capabilities under the control of the firm. Viewed in this light, exploitation depends upon prior exploration. During the early stages of the new product development process, a firm is prospecting for new wealth-creating opportunities. During this discovery period, the venture pursues an exploratory search involving basic research, invention, risk-taking, and building new capabilities with the goal of developing new knowledge or capabilities which it can subsequently exploit to create value (Cohen and Levinthal, 1990). Once potentially valuable knowledge and skills have been acquired through exploration, the firm then turns to exploitation activities. Thus, the exploration–exploitation model implies a sequence for the use of these processes by organizations. Exploitation cannot by definition take place without prior exploration (March, 1991). In reality, most firms engage in both activities simultaneously because they manage several concurrent projects at different stages

[1] While this paper is a large-scale empirical study, it has qualitative antecedents. Our fieldwork in the biotechnology industry enabled us to ground our model of the new product development path and to obtain qualitative data, some of which we draw on throughout this paper.

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in the product development process. Yet, from a theoretical viewpoint, the exploration–exploitation model implies that a firm's competency that is currently exploited must have been explored at some earlier time.

Subsequent research has linked the exploration–exploitation framework to strategic alliances (Koza and Lewin, 1998; Rothaermel, 2001a). Applying Koza and Lewin's (1998) conceptual understanding of alliances as motivated by either exploration or exploitation, recent empirical research indicated that a firm's propensity to enter exploration and exploitation alliances is related to the resource endowments of the firm (Park, Chen, and Gallagher, 2002). Building on these insights, we suggest a product development path beginning with exploration alliances and continuing through exploitation alliances, which should enhance the ability of technology ventures to discover, develop, and commercialize new products. This path implies a system of alliance utilization beginning with exploration followed by exploitation. Support for the entire product development system hinges upon the simultaneous positive relationship between each of the separate links constituting the model. We extend prior research by moving beyond motivations for alliance entry by looking for evidence of the effectiveness of an integrated exploration–exploitation alliance system in the context of new product development. Only if the complete model holds will we have found evidence for benefits derived from an exploration–exploitation alliance strategy.

Exploration alliances and products in development

Exploration alliances are entered into with the motivation to discover something new; they focus on the 'R' in the research and development process (Koza and Lewin, 1998). Envisioned outcomes and paybacks are distant in time and generally exhibit high variance. If we view the new product development process as a knowledge management process, then the hoped for outcome of the exploration process is the embodiment of new knowledge learned through exploration into a prototype product that can be extended into the testing and development process. Alternatively, exploration alliances may lead to the codification of new knowledge through patenting. In the biotechnology industry, for example, exploration collaborations are motivated by a desire to acquire basic knowledge that can be used to create novel molecular entities which are then entered into the development and regulatory process. Hence, we argue that exploration alliances predict products in development. An example of an exploration alliance is the collaboration between the biotechnology firm Biogen and the University of Zürich. Their cooperation led to the discovery of Intron A, the first product to enter clinical trials for the treatment of certain types of leukemia and hepatitis C.

It is the exploration stage of the new product development process that most previous studies have examined when linking firm allying to performance (Shan *et al*., 1994; Deeds and Hill, 1996; Baum *et al*., 2000). In our proposed model, however, we suggest that it is only the first step of the new product development process. Once the knowledge gained through exploration has become embodied in a prototype, the firm's attention then turns to exploitation processes.

Products in development and exploitation alliances

The filing of a patent or the entry of a product into the development and regulatory process signals that further new knowledge must be accessed and imbued into the product in order to exploit the knowledge gained through exploration. The completion of a prototype product creates an immediate need for certain complementary capabilities (e.g., legal and regulatory competence, manufacturing, marketing, and distribution). At this juncture, an entrepreneurial venture must make the decision to either go it alone or to collaborate with more established firms that then take on the commercialization of the new product. If forward integration is costly, time consuming, and risky, external funding through capital markets may not be a viable option (Lerner *et al*., 2003). On the other hand, established firms that have developed competencies in the downstream activities of the value chain are well positioned to collaborate with new ventures to commercialize new products. This collaboration is motivated by complementary assets and generates rents through economies of specialization (Teece, 1992).

The scenario above describes interfirm cooperation between biotechnology firms and established pharmaceutical companies at this point in the new product development process (Rothaermel, 2001a).

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Biotechnology firms focus on the 'R' of the research and development process, whereas large pharmaceutical companies focus on the 'D.' Prior research has shown that most alliances between new biotechnology firms and established pharmaceutical companies were initiated when the new drug candidate was about to enter clinical trials (Pisano and Mang, 1993). A biotechnology drug candidate reaching the product development stage signals a major milestone in the development process, since more than 95 percent of all drug candidates will not make it into clinical trials (Giovannetti and Morrison, 2000). Uncertainty has been drastically reduced once a product is ready to enter the development stage. By embodying knowledge created through exploration into a prototype product, a technology venture is able to distinguish itself and to signal the quality of its project. This intermediate success generates alliance opportunities for the biotechnology firm. For example, when interviewed, H. Stewart Parker, CEO of the biotechnology firm Targeted Genetics, indicated that every time there is an article about Targeted Genetics' successful product development in the *Wall Street Journal*, the telephone will ring off the hook with pharmaceutical companies calling and offering alliance opportunities.

Established pharmaceutical companies have long-standing routines and competencies to manage a new drug through the regulatory process and then to market it via their armies of detail people, which are often 15,000 strong. In addition, large pharmaceutical companies tend to have the resources to finance this most costly and time-consuming part of the development process, and they are often short of innovative products in their own research pipelines. Moreover, some empirical evidence exists showing that pharmaceutical companies possess an informational advantage in evaluating the research efforts of biotechnology firms over the capital markets (Majewski, 1998; Lerner *et al*., 2003). It is argued that the existing pharmaceutical companies generally see a greater potential in the new biotechnology than capital markets, and thus they apply a smaller discount rate on capital when funding biotechnology research. This in turn implies that pharmaceutical companies tend to be relatively cheaper sources of capital for biotechnology firms than the capital markets. Taken together, we argue that a technology venture's products in development indicate the need for complementary assets and may create access to them through exploitation alliances with established companies.

Exploitation alliances and products on the market

Exploitation alliances focus on the 'D' in the research and development process and are entered into with the goal to join existing competencies across organizational boundaries in order to generate synergies, which are then shared across the partners (Koza and Lewin, 1998). Exploitation alliances can be characterized by the union of complementary assets (Teece, 1986). Successful exploitation enables the firm to commercialize the knowledge gained through exploration. New biotechnology firms often focus on creating new drugs, which are then commercialized by established pharmaceutical companies.

Above, we described how the biotechnology firm Biogen has used an exploration alliance with the University of Zürich to discover Intron A, the first biotechnology drug for the treatment of leukemia and hepatitis C to reach clinical development. Subsequently, Biogen decided to commercialize this innovative drug through an exploitation alliance with the pharmaceutical company Schering-Plough. In particular, Biogen entered an exclusive licensing agreement with Schering-Plough, which took on the clinical trials and regulatory activities of the product as well as its marketing, distribution, and sales. This example shows that Biogen was able to discover and develop a new drug through an exploration alliance with a university, which it then commercialized through an exploitation alliance with an established pharmaceutical company. In sum, we argue that exploitation alliances are one possible organizing mode to commercialize new products and thus predict products on the market.

Firm allying and new product development

We presented each individual link of our proposed product development path which indicated three separate hypotheses. However, we would like to emphasize that we set out to advance an integrated product development system. This implies that the linkages between each step in the product development path must hold simultaneously to provide support for our model, which explains the process of embodying knowledge into products

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from discovery to market commercialization via interfirm cooperation. This theoretical model of the product development path warrants a system-level hypothesis.

> *Hypothesis 1: There exists a system of new product development linking exploration alliances to products on the market with exploration alliances predicting products in development, products in development predicting exploitation alliances, and exploitation alliances predicting products on the market.*

Figure 1 depicts our research model and summarizes our hypothesized product development path beginning with a technology venture's exploration alliances and ending with products on the market. The model also depicts a variety of control variables that may impact the proposed product development process. In the methods section, we discuss each variable in detail.

Moderating effect of firm size on new product development path

At each stage of the proposed product development path, a technology venture must decide to either forwardly integrate or to collaborate. If markets were efficient, firms would have no reason to vertically integrate. Each organization would focus on its respective competencies in a different stage of the product development path, and products would be commercialized through transactions in the market for know-how. All participants could benefit from economies of specialization and each organization would fully extract the rents reflecting their value added in the product development process. However, transaction cost economics has advanced theoretical arguments that propose that markets may not always function according to the market efficiency hypothesis (Williamson, 1985). Following these arguments, Pisano (1997) has suggested that the market for know-how, which emerges when different organizations possess complementary competencies, may not always function properly.

When analyzing our proposed product development path, several potential frictions in the market for know-how that can inhibit an efficient market are noteworthy. Sources of market imperfections include the challenges of negotiating and enforcing contracts as well as the risks and costs associated with making specialized investments in the face of uncertainty (Williamson, 1985). Frictions can also arise from appropriability problems when intellectual property rights are not fully specified and sufficiently protected (Teece, 1986) or by attempting to develop and transfer tacit knowledge across organizational boundaries (Lane and Lubatkin, 1998). Empirical work provided support for the notion that firms tend to vertically integrate when the costs of transacting in the market exceed those of vertical integration (Klein, Crawford, and Alchian, 1978; Monteverde and Teece, 1982; Pisano, 1990).

Exploration alliances are exposed to the challenge of negotiating and structuring contracts in the face of uncertainty, which frequently causes frictions between the partners over intellectual property. Exploration alliances are further exposed to the difficulty of coordinating and transferring tacit knowledge across the partner organizations. Many technology ventures get their start in universities, which either spin off new ventures, or scientists become entrepreneurs, often in combination with venture capitalists. In their early stages, those new ventures generally rely on exploration cooperations with the organizations they originated from. Disputes over intellectual property rights are quite frequent at this stage as the universities and new technology ventures argue over who owns what rights.

For example, the founding of Genentech in 1976, later the first public biotech firm, was based on the idea of commercializing scientific breakthroughs accomplished at Stanford University and the University of California. Incidentally, Herbert Boyer, one of the scientists at the University of California who was involved in the revolutionary scientific breakthroughs, was also a co-founder of Genentech. University scientists becoming, in one form or another, involved in commercially driven biotechnology firms is commonplace in this industry (Zucker, Darby, and Armstrong, 2002). Such close involvement of universities and biotechnology firms often end up in legal disputes over who owns the rights to certain patents, as illustrated in the University of California vs. Genentech legal dispute (Managing Intellectual Property, 1999). Thus, as technology ventures grow, they might prefer in-house exploration for certain projects to avoid being exposed to the hazards of allying in the market for know-how.

In a similar manner, exploitation alliances may also be exposed to hazards stemming from disputes

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over intellectual property rights and to hazards resulting from necessary investments in specialized assets. Legal disputes over patent infringements are quite frequent at this stage of the product development process, as the new ventures license their technology to established firms that take on the commercialization. For example, the first biotechnology drug to reach the market was Humulin, a human insulin, which was discovered and developed by the biotechnology firm Genentech and commercialized by the pharmaceutical company Eli Lilly. However, Genentech later sued Lilly, accusing that it misused materials provided by Genentech to commercialize recombinant human insulin. Further, necessary investments in specialized assets to develop the new technology exposes both the new venture and the firm that commercializes the technology to opportunistic behavior (Williamson, 1985).

Aghion and Tirole (1994) developed a theoretical model to analyze the organization of research and the allocation of ownership for an innovation between a research firm and a customer firm, the financier of the research. The Aghion-Tirole model led to two important predictions of interest to our research. First, to maximize research efficiency, and thus joint value creation, control rights should be assigned to the research firm whenever the value of the final output depends more on the marginal efficiency of the research effort than on the marginal impact of the financial investment. Second, a cash constraint on the part of the research firm causes an inefficient outcome due to the financier's use of its bargaining power to retain greater ownership. In essence, if research firms, such as biotechnology ventures, face cash constraints that limit their bargaining power, then their established alliance partners are able to use their financial power opportunistically to drive down the price of the research and to gain greater ownership at the expense of the research firm.

Above, we argued that technology ventures, due to their initial resource constraints, engage in an exploration and exploitation alliance strategy when embodying new knowledge throughout the product development process by transforming discoveries into commercialized products. However, as predicted by Aghion and Tirole (1994) and empirically supported by Lerner and Merges (1998) and Lerner *et al*. (2003), financially constrained firms tend to give up too much ownership of the innovation when entering an alliance. Lerner and Merges concluded that 'the most profound effect on the allocation of control rights, at least in technology alliances . . ., is the financial condition of the R&D firm, rather than mutual concern about maximizing joint value' (Lerner and Merges, 1998: 153). Alliances, as incomplete contracts, inherently pose certain contracting hazards, which appear to be exacerbated by firm financial constraints.

Moreover, technology ventures generally possess an informational advantage in evaluating the quality of their development projects (Lerner *et al*., 2003). This situation can lead to a lemons problem in the market for know-how (Akerlof, 1970; Pisano, 1997).[2] In particular, a technology venture generally pursues several concurrent projects, and due to its intimate familiarity with the projects built over long periods of time it has a reasonable understanding of which projects show the most promise. Since the established firm attempting to commercialize a project offered by the technology venture has no such insider information to judge whether a project offered for collaboration is a promising one or not, it will discount the project to hedge against lemons and thus offer a reduced deal to the new venture.

As Akerlof's example of used cars has demonstrated, information asymmetry can lead to the perverse effect that sellers will only offer lemons if the price the buyers offer is below the value the sellers attach to good cars. Applying this analogy to the market for collaborative know-how in biotechnology, Pisano (1997) found empirical support for a lemons problem in the market for drug development projects reaching clinical trials. As a new venture grows and accrues internal resources to finance its high prospect projects, it will tend to keep them in-house vs. developing them through alliances with a larger partner. Thus, a lemons problem, in combination with the downward pricing pressure in the market for collaborative know-how due to the weak bargaining

[2] The following briefly summarizes the lemons problem (Akerlof, 1970). In the market for used cars, only two types of cars are sold: good cars and bad cars (lemons). Good cars are worth $8000 and bad ones are worth $4000. Moreover, only the seller knows if his/her car is a good one or a lemon. Assuming the market supply is split equally between good and bad cars, then the *ex ante* probability of buying a lemon is 50 percent. Buyers are aware of the general possibility of buying a lemon and thus would like to hedge against it. Therefore, they include a discount and offer $6000 for a used car. This discounting strategy has the perverse effect of crowding out good cars if the sellers perceive their value to be above $6000. Assuming that to be the case, all that are left in the market for used cars will be lemons.

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position of the numerous small, under-financed research firms, creates a situation in which even a well-financed research firm has an incentive to withhold promising projects, despite its improved bargaining position.

The gradual tendency to substitute internal resources for external ones as the technology venture grows is also supported by the theoretical predictions of the optimal capital structure model (Myers, 1984; Myers and Majluf, 1984). Technology ventures generally find themselves struggling to acquire resources from skeptical investors who have difficulty judging the quality of a specific project. According to the pecking order theory of optimal capital structure, a firm's preferences for obtaining capital will follow a hierarchy with a preference for internal over external sources of capital because of asymmetric information and signaling problems. Therefore, firms allocate their available internal resources first before seeking external resources for the remainder. The strength of the preference for internal resources to finance promising projects is based on the costs associated with information asymmetries between the firm and external resource providers (Myers and Majluf, 1984; Shyam-Sunder and Myers, 1999) and the risks of expropriation of knowledge due to opportunistic actions by the partner (Williamson, 1985).

Initially, new technology ventures with small resource endowments and private information about valuable projects will be forced to exchange ownership of their projects at a suboptimal price (Aghion and Tirole, 1994; Lerner and Merges, 1998). This implies that firms with constraint resources will be forced to be over-reliant on external resources in the new product development process, leaving them open to be undervalued and to the risks of having their core knowledge assets expropriated. Recent empirical work provides some evidence for this notion with the finding that a substantial amount of the value created through small firm–large firm alliances was appropriated by the larger partners (Rothaermel, 2001b). Moreover, alliances between small R&D firms and large established firms, where more control rights were given to the large firm that financed the research, tended to be less successful and were more likely to be renegotiated when equity markets became more favorable (Lerner *et al.*, 2003). Taken together, as a technology venture grows and acquires more resources, it will tend to minimize the risk of expropriation by acting on its preference to retain promising projects for in-house development, and thus commensurately decrease its reliance on strategic alliances to discover, develop, and commercialize new products.

Hypothesis 2: The product development path leading from exploration alliances to products on the market is moderated negatively by firm size.

METHODS

Research setting

The research setting is the biotechnology industry. The emergence of biotechnology can be interpreted as a radical process innovation that broke the barriers of entry into the pharmaceutical industry, among other industries (Pisano, 1990). Since the early 1970s, about 1600 new biotechnology firms have emerged to commercialize this technological breakthrough. The commercialization of biotechnology is characterized by extensive interfirm cooperation. Indeed, the biotechnology industry has been identified as the industry with the highest alliance frequency among several industries characterized by high alliance activity (Hagedoorn, 1993).

The drug discovery and development is fraught with extremely high uncertainty. The entire process may extend more than 15 years and can cost over $500 million for a single drug.[3] The odds of a discovered molecule succeeding in the development process are extremely low. For every 10,000 compounds screened, 250 (2.5%) so-called lead candidates make it into preclinical testing. Out of those lead candidates, five (2%) enter clinical testing, 80 percent pass phase I, 30 percent pass phase

[3] The drug discovery and development process can be broken down into distinct sequential stages (Giovannetti and Morrison, 2000: 46–47). The discovery stage can take anywhere between 2 and 10 years. In the next stage, which can take up to 4 years, a lead drug candidate is developed and pre-clinical testing is undertaken. A lead candidate then enters phase I of clinical testing, which can take up to 2 years. In this phase, the lead candidate is administered to 20–30 healthy volunteers and its safety and dosage are evaluated. In phase II, which can take up to 2 years, the drug is given to 100–300 patient volunteers to check for efficacy and side effects. In phase III, which can take up to 3 years, the drug is administered to 1000–5000 patient volunteers to monitor reactions to long-term drug usage. The next stage, FDA review and approval, can take up to 2 years. This is followed by a 2-year post-marketing testing period.

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II, and 80 percent pass phase III of the clinical trials. Thus, for every 10,000 compounds screened, one drug will be approved by the FDA (Giovannetti and Morrison, 2000). This implies that the *ex ante* probability for a molecule to develop into a commercialized drug is 0.01 percent.

Those numbers also imply that exploration and exploitation alliances both carry uncertainty with respect to their potential outcome. When studying the impact of equity financing cycles on the performance of collaborative R&D alliances between small biotechnology firms and their larger partners, Lerner *et al*. (2003: 434) found that only 14 percent out of a sample of 200 randomly drawn alliances begun since January 1980 resulted in an approved drug by December 1998. When considering only alliances that were entered when the drug development had already progressed to either phase I or phase II of clinical trials, the reported success rate was about 26 percent. These numbers indicate that, on the average, the majority of all alliance projects, regardless whether they focus on exploration or exploitation, will not result in commercialized products. They also indicate that uncertainty declines as the project moves along in the product development process, thus exploration alliances generally entail higher uncertainty than exploitation alliances.

Data and sample

We identified all new biotechnology firms fully dedicated to human therapeutics listed in BioScan,[4] i.e., all firms that were engaged in developing *in vivo* therapeutics. This segment of the biotechnology industry comprises new biotechnology firms engaged in the research, development, and commercialization of therapeutics that are placed inside the human body (*in vivo*) as opposed to *in vitro* therapeutics that are used outside the human body. We limited our sample to *in vivo* therapeutics since the firms engaged in this segment of biotechnology are exposed to extensive regulatory requirements (e.g., FDA), which bring with them detailed reporting of products under development. Focusing on human therapeutics also allowed us to create a homogeneous sample, while controlling for industry idiosyncrasies. This process yielded a sample of 325 biotechnology firms.

In the next step, we obtained each firm's alliance history. BioScan lists detailed qualitative information about each of the firms' alliances, such as the focal firm's partners, the month and year when the alliance was entered, whether the alliance is governed by an equity or contractual arrangement, and what area of the industry value chain it covers (research, drug discovery, development, clinical trials, FDA regulatory process, marketing and sales). We based our classification scheme concerning different alliance types on Koza and Lewin's notion that a firm's motivation to enter an alliance is driven by the desire 'to exploit an existing capability or to explore for new opportunities' (Koza and Lewin, 1998: 256).[5] Firms enter exploration alliances to discover something new jointly with an alliance partner, while exploitation alliances are 'associated with increasing the productivity of employed assets—improving and refining existing capabilities and technologies' (Koza and Lewin, 1998: 256). Thus, in classifying a biotechnology firm's alliances as either exploration or exploitation, we focused on the motivation for and activities of the alliance as specified by the alliance partners. Our classification system also corresponds to that employed by Park *et al*., who, when studying alliance formation by semiconductor start-ups, categorized exploration alliances as those with a joint research and development component, and 'alliances oriented toward exploiting existing resources ... were classified as exploitation alliances' (Park *et al*., 2002: 534). Accordingly, we coded each of the biotechnology firms' alliances that focused on basic research, drug discovery and development as exploration alliances, and alliances that were targeted towards commercialization (clinical trials,

[4] *BioScan*, which is published by American Health Consultants, provides one of the most comprehensive publicly available directories covering the global biotechnology industry. It has been used in a number of prior studies (cf. Shan *et al*., 1994; Powell, Koput, and Smith-Doerr, 1996; Lane and Lubatkin, 1998; Rothaermel, 2001a).

[5] While we followed the theoretical work by Koza and Lewin (1998), and focused on the *intent* or *motivation* of an alliance in categorizing it either as exploration or exploitation, other scholars have advanced different definitions. For example, Rosenkopf and Nerkar (2001) use organizational and technological boundaries to define four different types of exploration. Accordingly, alliances go beyond local search as they are boundary spanning, and thus are considered exploration activities.

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FDA regulatory process, and marketing and sales) were coded as exploitation alliances.[6]

Measures

Our hypothesized product development path proposes linkages between four key variables: exploration alliances, products in development, exploitation alliances, and products on the market. We operationalized a firm's products in development as a count variable of each firm's biotechnology products in development that have successfully entered clinical trials but have not yet reached the market for pharmaceuticals. A firm's products on the market is a count variable of each firm's biotechnology products that successfully completed all stages of the product development process and are now commercialized. A firm's exploration alliances is a count variable of its alliances that focus on the upstream activities of the value chain (basic research, drug discovery and development). Conversely, a firm's exploitation alliances is a count variable of its alliances that focus on the downstream activities of the value chain (clinical trials, FDA regulatory process, and marketing and sales).

We employed several control variables that may impact upon the proposed new product development path (Figure 1). We controlled for the average age of a firm's exploration and exploitation alliances in months since older alliances are more likely to yield products in development and on the market than younger alliances. We controlled for a firm's innovativeness through including a count variable of its patents received between 1991 and 1995. Shan *et al.* (1994) and Baum *et al.* (2000) proxied a firm's innovativeness in a similar manner.[7] A 5-year window for patenting attenuates annual fluctuations and thus may capture a biotechnology firm's patenting propensity more accurately since numerous firms in the sample are small firms that do not receive many patents per year, if any. Further, based on the time lag between taking stock of a firm's patenting and its new product development, exploitation alliances, and products on the market, it is reasonable to assume that a firm's patenting propensity may have an influence on them. Using a 5-year time window is also consistent with prior research attempting to proxy a firm's innovativeness (Stuart and Podolny, 1996; Ahuja, 2000).[8] We obtained the patenting data from the U.S. Patent and Trade Mark Office.

We included a ratio of a firm's equity alliances over its total alliances to control for the impact of a firm's preference for equity vs. nonequity alliances on the product development path. We controlled for firm age, assuming that older firms are more likely to have more products in development and have entered more alliances (Sørensen and Stuart, 2000). We also controlled for each firm's degree of technological diversity through the inclusion of a count variable representing the number of biotechnology subfields in which the firm participated (Shan *et al.*, 1994). We further controlled for the ownership status of the firm (1 = public firm) and whether the firm was a subsidiary or independent (1 = subsidiary). We included a dummy variable to distinguish between U.S.-based and non-U.S. biotechnology companies (1 = U.S. firm) to control for institutional differences (Hennart, Roehl, and Zietlow, 1999). Finally, we controlled for firm size by using the number of employees as a proxy. Firm size is often measured in revenues or market share; however, most biotechnology firms do not have a positive revenue stream at this point. Thus, measuring firm size in terms of employees provides a reasonable alternative (Shan *et al.*, 1994).

Estimation procedure

We propose a theoretical model of an exploration–exploitation alliance strategy in new product development that includes three dependent variables: products on the market, exploitation alliances, and products in development (Figure 1). Two of the four variables describing the proposed product development path (products in development and exploitation alliances) are at the same time dependent variables as well as independent variables. This indicated testing Hypothesis

[6] A second researcher coded independently 10 percent of the sample to assess inter-rater reliability, which we found to be 0.94. This is well above the conventional cut-off point of 0.70 (James, 1982; Cohen and Cohen, 1983).

[7] Theoretically, a quality weighted measure of patenting (e.g., adjusted by citations) provides an alternative to assess a firm's innovativeness. However, the recency of the emergence biotechnology in combination with the patent citation time lag made this approach infeasible. A raw count of patents provides a reasonable proxy since prior research has shown that a firm's raw patent count is highly correlated with the quality of its patents (Stuart, 2000).

[8] We also conducted a robustness check applying alternative time lags and time windows. All significant relationships remained robust.

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1 using structural equation modeling (Anderson and Gerbing, 1988). This approach is appropriate here since it allows us to test a system of structural equations, where a dependent variable in one relationship becomes an independent variable in the subsequent relationship. We estimated the following recursive system describing the proposed product development path by a maximum likelihood procedure for structural equation models (Bentler, 1995):

Products on the market
$= f$(Exploitation alliances, Controls)

Exploitation alliances
$= f$(Products in development, Controls)

Products in development
$= f$(Exploration alliances, Controls)

To assess the threat of reverse causality, we applied two separate procedures. First, we estimated an alternative recursive model with the structural equations describing the reverse path leading from products on the market, via exploitation alliances and products in development, to exploration alliances. Here, we found that this model did not provide an acceptable overall fit with the data; moreover, the path itself was not significant. Second, we applied a two-stage least squares regression model to assess reverse causality (Shan *et al*., 1994; Greene, 1997). The results indicated that the product development path runs from exploration alliances to products in development, while the reverse causality was not supported.

The interaction effects stipulated in Hypothesis 2 were tested using a negative binomial regression model with a maximum likelihood procedure. The negative binomial regression model treats the dependent variables of interest (products in development, exploitation alliances, and products on the market) as count variables, while estimating heterogeneity. This relaxes the restrictive assumption of mean and variance equality inherent in the Poisson model and also accounts for omitted variable bias (Walker, Kogut, and Shan, 1997).

We tested for moderation through the inclusion of the independent variables and the interaction terms between the respective independent variables in the same regression model. Such a moderated regression approach is a conservative method for examining interactions since the interaction term is tested for significance after all other direct effects are controlled (Aiken and West, 1991). Moreover, testing for a negative moderation effect of firm size on the product development path requires significant findings for each link and thus support for three different interaction terms. We standardized the variables, prior to creating the interaction terms, to improve their interpretability and to reduce the threat of multicollinearity (Aiken and West, 1991).

RESULTS

The average biotechnology firm in our sample has entered into three exploration and five exploitation alliances, has one product on the market, five products in development, holds five patents, has 161 employees, is about 10 years old, and participates in six different technological subfields. Sixty-nine percent of the firms are public, while 7 percent of the firms are subsidiaries. Seventy-eight percent of the firms are U.S. based. About 4 percent of all alliances are equity arrangements. The 325 firms in our sample entered a total of 2565 alliances in the 25-year period between 1973 and 1997. These 2565 alliances split into 1072 (42%) exploration alliances and 1493 (58%) exploitation alliances. The number of exploitation alliances is significantly larger than the number of exploration alliances ($p < 0.001$). A descriptive statistic of the variables as well as a correlation matrix can be found in Table 1, while Figure 2 and Table 2 depict the results.

Figure 2 depicts the structural relationships among the theoretical constructs for testing Hypothesis 1. While we estimated the structural equation model including all of the relationships presented in Figure 1, Figure 2 only shows the significant relationships for the sake of visual clarity. Results from structural equation models are evaluated with respect to their model fit (Byrne, 1994). The model proposed in Figure 1 provides an acceptable overall model fit with the sample data as indicated in the following statistics. The likelihood ratio chi-square statistic is 117.92 for 47 degrees of freedom. This implies that the chi-square statistic for one degree of freedom is 2.51 (= 117.92/47), well below the significant chi-square of 3.84 for $p < 0.05$ (and also below the significant chi-square of 2.71 for $p < 0.10$). A nonsignificant chi-square is desired as it indicates that the model is not significantly different from the underlying data. In

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Table 1. Descriptive statistics and correlation matrix

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Products on market	1.21	2.24													
2. Exploitation alliances	4.59	5.66	0.49												
3. Age exploitation alliances	34.60	26.28	0.12	0.24											
4. Products in development	5.14	4.06	0.17	0.43	0.05										
5. Exploration alliances	3.29	3.75	0.28	0.52	0.04	0.43									
6. Age exploration alliances	27.03	23.32	0.01	0.19	0.25	0.16	0.31								
7. Patents	4.88	13.95	0.50	0.61	0.12	0.34	0.51	0.15							
8. Equity ratio	0.04	0.16	0.01	−0.01	−0.11	0.09	0.04	−0.05	0.02						
9. Firm age	9.60	4.61	0.38	0.33	0.34	0.18	0.14	0.22	0.35	−0.03					
10. Technological diversity	6.22	4.71	0.29	0.45	0.08	0.32	0.45	0.21	0.41	0.01	0.27				
11. Public firm	0.69	0.46	0.04	0.18	0.02	0.22	0.10	0.03	0.10	−0.03	0.17	0.06			
12. Subsidiary	0.07	0.27	0.04	0.01	0.16	−0.07	0.02	0.06	−0.03	−0.05	0.05	0.03	−0.18		
13. U.S. firm	0.78	0.42	−0.09	0.12	−0.02	0.14	0.09	0.05	0.10	0.05	0.01	0.04	0.11	−0.04	
14. Firm size	161.17	573.19	0.55	0.58	0.09	0.36	0.58	0.07	0.70	0.03	0.23	0.40	0.09	0.01	0.06

$n = 325$.

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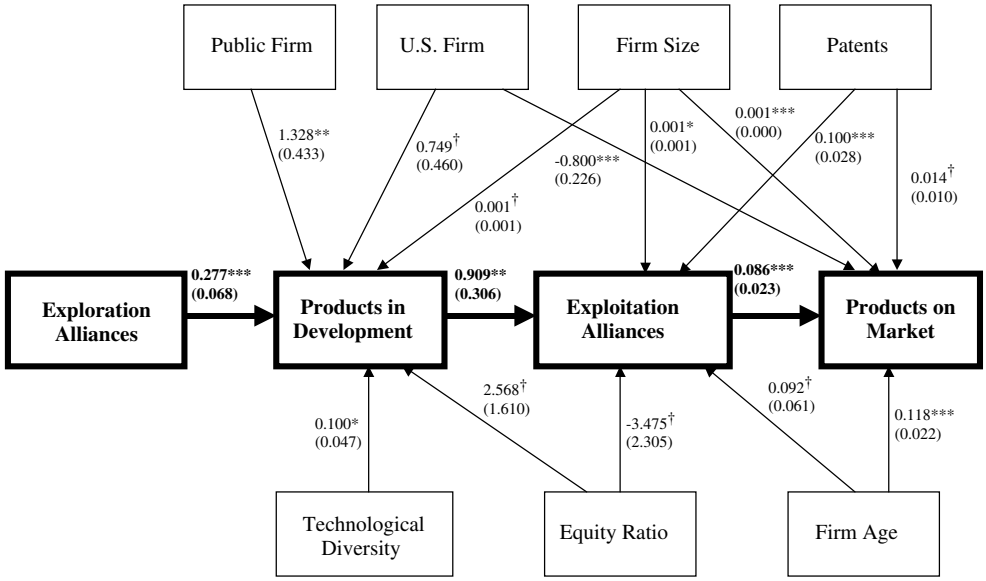

Model Fit Assessment: Normed Fit Index (NFI): 0.902;
Comparative Fit Index (CFI): 0.936;
LISREL Goodness of Fit (GFI): 0.951;
Root Mean Error of Approximation (RMSEA): 0.068;
† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;
Standard Errors in Parentheses.

Figure 2. Structural equation modeling results

general, a value for the ratio of chi-square over degrees of freedom of less than 3.0 indicates a good fit (Carmines and McIver, 1981). In addition, several other evaluations are important in assessing the fit of the model: the normed fit index (NFI), the comparative fit index (CFI), and the LISREL goodness of fit index (GFI) should each be greater than 0.90, and the root mean error of approximation (RMSEA) should be smaller than 0.10 for a good fitting model (Byrne, 1994). Our results reveal that the NFI is 0.902, the CFI is 0.936, the GFI is 0.951, and the RMSEA is 0.068 with a 90 percent confidence interval of (0.053, 0.083). We also conducted a Lagrange multiplier test and found that no alternative specification of the parameters would have led to a model that better represented the data.

Hypothesis 1 suggests an integrated new product development path in which a high-technology firm's exploration alliances predict its products in development, which in turn predict the firm's exploitation alliances, and they in turn predict the firm's products on the market. The results depicted in Figure 2 provide support for the proposed new product development path. The results indicate that a firm's exploration alliances are significant in predicting the firm's products in development ($p < 0.001$), while a firm's products in development in turn are a significant predictor of the firm's exploitation alliances ($p < 0.01$), and a firm's exploitation alliances are significant in predicting a firm's products on the market ($p < 0.001$).

The results further indicate that a firm's degree of technological diversity is positively associated with its products in development ($p < 0.05$) and that public firms tend to have more products in development ($p < 0.01$). We also find that firms that have more equity alliances, that are U.S. based, and that are larger in size tend to have more products in development ($p < 0.10$). Additional results demonstrate that a firm's patents ($p < 0.001$) and size ($p < 0.05$) are significant in predicting the number of its exploitation alliances. We also find that a firm's age is marginally significant in predicting its exploitation alliances. Further, a firm's preference for equity alliances is

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Table 2. Regression results

Dependent variable	Products in development Model 1	Products in development Model 2	Exploitation alliances Model 3	Exploitation alliances Model 4	Products on market Model 5	Products on market Model 6
Intercept	1.587***	1.623***	1.386***	1.169***	−0.082	−0.036
	(0.038)	(0.038)	(0.041)	(0.086)	(0.083)	(0.089)
Patents	0.042	0.118*	0.127*	0.111*	0.067	0.111
	(0.052)	(0.057)	(0.066)	(0.061)	(0.101)	(0.106)
Equity ratio	0.073*	0.053†	−0.060†	−0.086*	−0.028	−0.028
	(0.038)	(0.036)	(0.054)	(0.053)	(0.088)	(0.089)
Firm age	0.017	−0.025	0.157**	0.136**	0.455***	0.407***
	(0.042)	(0.043)	(0.053)	(0.051)	(0.085)	(0.088)
Technological diversity	0.135***	0.056†	0.146**	0.096*	0.024	−0.119†
	(0.042)	(0.042)	(0.049)	(0.048)	(0.087)	(0.095)
Public firm	0.137***	0.117***	0.163***	0.138**	−0.058	−0.151*
	(0.041)	(0.039)	(0.050)	(0.049)	(0.085)	(0.088)
Subsidiary	−0.036	−0.047†	0.003	0.002	0.082	0.092†
	(0.041)	(0.039)	(0.048)	(0.047)	(0.079)	(0.083)
U.S. firm	0.082*	0.075*	0.083*	0.042	−0.244***	−0.281***
	(0.040)	(0.038)	(0.049)	(0.048)	(0.077)	(0.078)
Firm size	0.075†	0.0459***	0.091†	0.654**	0.240**	1.002**
	(0.051)	(0.120)	(0.062)	(0.267)	(0.104)	(0.304)
Age exploration alliances		0.028				
		(0.042)				
Exploration alliances		0.181***				
		(0.048)				
(Exploration alliances × Size)		−0.103***				
		(0.023)				
Products in development				0.049***		
				(0.013)		
(Products in development × Size)				−0.039**		
				(0.017)		
Age exploitation alliances						−0.091
						(0.088)
Exploitation alliances						0.302**
						(0.099)
(Exploitation alliances × Size)						−0.190**
						(0.062)
Log likelihood	−814.36	−795.85	−792.14	−781.21	−442.78	−432.07
Chi-square	347.15***	384.19***	876.50***	898.36***	102.14***	123.56***
Improvement over base ($\Delta\chi^2$)		37.04***		21.86***		21.42***

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; standard errors in parentheses

negatively associated with its exploitation alliances ($p < 0.10$). The results further indicate that a firm's age ($p < 0.001$) and size ($p < 0.001$) are significant positive predictors of a firm's products on the market, while a firm's patents are marginally significant in predicting a firm's products on the market. Finally, U.S. firms tend to have significantly fewer products on the market ($p < 0.001$) than their non-U.S. competitors.

Further insights can be gleaned from comparing the results for the same parameters across the three equations. Firms that hold more patents tend to enter more exploitation alliances and have a greater number of products on the market, although patents are nonsignificant in predicting the firm's products in development. Firms with a higher number of equity alliances tend to have more products in development but enter fewer exploitation alliances. A preference for equity alliances is insignificant in predicting a firm's products on the market. Older firms tend to have more exploitation alliances and products on the market, while firm age is nonsignificant in explaining a firm's products in development. Firms that diversified in

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a larger number of technological subfields tend to have more products in development, although a firm's diversity has no significant impact on either the number of its exploitation alliances or its products on the market. Public firms tend to have more products in development, but the ownership status of the firm is not relevant when predicting its exploitation alliances or products on the market. U.S. firms have on the average more products in development but fewer products on the market. Nationality is insignificant in predicting exploitation alliances. Finally, larger firms tend to have more products in development, more exploitation alliances, and more products on the market.

Hypothesis 2 advances the notion that the path leading from exploration alliances to products on the market is moderated negatively by firm size. Testing this hypothesis implied an investigation of three different interaction terms. More specifically, we needed to test whether each of the links between (1) exploration alliances and products in development, (2) products in development and exploitation alliances, and (3) exploitation alliances and products on the market are moderated negatively by firm size. The results are presented in Table 2. Models 1, 3, and 5 are the three respective baseline models. Models 2, 4, and 6, each of which represent a significant improvement over their respective baseline model ($p < 0.001$), depict the results for the size interaction effects. Model 2 reveals that the interaction between a technology venture's exploration alliances and its size is negative and significant ($p < 0.001$), indicating that as the venture becomes larger, its exploration alliances become less important in predicting its new product development. Model 4 shows that the interaction between a venture's products in development and its size is negative and significant ($p < 0.01$). This implies that as the venture grows, its new product development becomes less critical in explaining the venture's exploitation alliances. The results from Model 6 demonstrate that the interaction between a venture's exploitation alliances and its size is also negative and significant ($p < 0.01$), indicating that as the venture becomes larger, its exploitation alliances become less crucial in explaining its products on the market.

Taken together, we find that all three hypothesized size interaction effects are negative and significant. This provides support for Hypothesis 2 and suggests that the product development path leading from exploration alliances to products on the market is moderated negatively by firm size. Both types of alliances become less relevant for the firm's new product development as the technology venture accrues more internal resources. Moreover, the exploitation–size interaction effect ($\beta = -0.190$) is significantly more negative than the exploration–size interaction effect ($\beta = -0.103$; $p < 0.05$), which implies that exploitation alliances tend to lose their relevance faster than exploration alliances as the technology venture grows in size.

To gain further insights into the nature of the moderation effects between firm size and the different types of alliances on products in development and on the market, we plotted the interactions based on the results obtained in Models 2 and 6 (Aiken and West, 1991). Figure 3(a) reveals a negative relationship between firm size and products in development for a high number of exploration alliances. A similar negative relationship is depicted in Figure 3(b) when applying products on the market as a dependent variable. Comparing both figures reveals that exploitation alliances appear to be more critical than exploration alliances for smaller firms considering the performance gap for firms with a low number vs. a high number of alliances. Moreover, Figures 3(a) and 3(b) indicate a positive relationship between firm size and products in development or products on the market for a low number of the respective alliance type. The best-performing larger firms pursue only a low number of exploration and exploitation alliances. This implies that larger firms tend to use vertical integration for some development projects since the results from the direct effects revealed that larger firms have significantly more products in development and on the market.

DISCUSSION

We found support for an integrated product development path leading from exploration alliances, via products in development and exploitation alliances, to products on the market. On the average, new technology ventures that use an exploration–exploitation strategy in their product development efforts tend to have more products in development and on the market. However, we also found that this product development path is moderated negatively by firm size. It appears that as the

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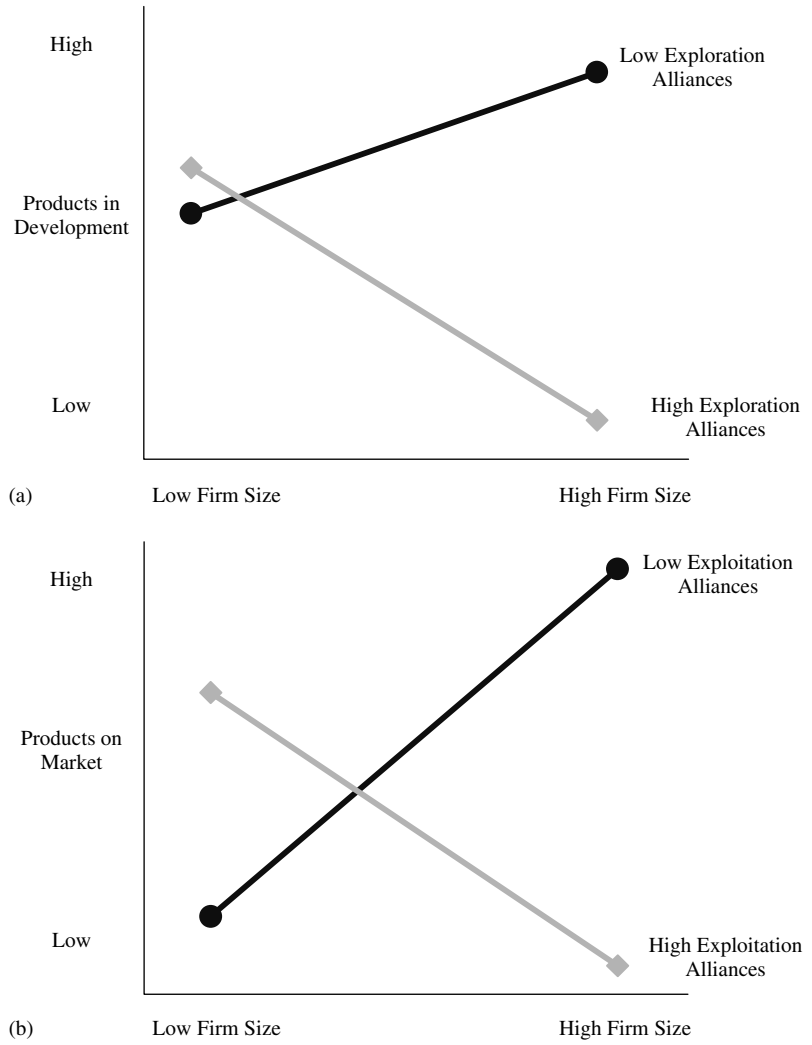

Figure 3. Interactions between alliance type, firm size, products in development, and products on market. (a) Exploration alliances, firm size, and products in development. (b) Exploitation alliances, firm size, and products on market

technology ventures grow, they are in a position to retain their most promising projects for in-house exploration and exploitation. This interpretation resonates with Pisano's (1997) finding that collaborative development projects between biotechnology and pharmaceutical companies had a higher probability of termination than projects pursued by the biotechnology ventures alone through vertical integration.

The results suggest an understanding of new product development as a knowledge management process that requires a firm to imbue the project with different types of knowledge at the different stages of the process (Madhavan and Grover, 1998). Moreover, drawing on the exploration–exploitation learning framework allows us to gain insights when applied to the context of strategic alliances in the new product development process. The evidence supports Koza and Lewin's (1998) theoretical notion that firms enter alliances with different motivations and different goals. The fact that exploration alliances predict products in development, which in turn predict exploitation alliances, and that exploitation alliances predict products on the market, indicates not only that there are different motivations and goals for the different types of alliances, but also that different alliance types precede different

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outcomes. These outcomes built on each other in a sequential manner and thus contribute to a integrated new product development process.

Biogen's commercialization of Intron A can be described by the product development process advanced in this paper. Biogen used an exploration alliance with the University of Zürich and an exploitation alliance with Schering-Plough to discover, develop, and commercialize Intron A. This product development strategy was successful for Biogen as Intron A reached over $1 billion in sales in 2001. While Biogen shares this revenue stream with its alliance partners, Biogen would have perhaps not been able to discover and commercialize Intron A on its own considering the difficulty of going it alone. Even if Biogen would have been able to discover, develop, and commercialize Intron A alone, it probably would have taken much longer.

Our results also seem to support the conjectures of transaction cost economics (Williamson, 1985) and the pecking order hypothesis of the optimal capital structure model (Myers, 1984). When the hazards in the market for collaborative know-how become too high, firms tend to vertically integrate promising projects and fund them with internal resources. The fact that firm size negatively moderates the impact of firm allying in each of the hypothesized links in the proposed product development system seems to indicate that internal resources are preferred to external resources by technology ventures to fund promising projects, regardless whether the activity concerns exploration or exploitation. Thus, while alliances appear to be one possible organizing mode of developing new products, the movement away from alliances as the venture grows indicates that they may be a risky strategy in which the smaller firms may be exposed to the risk of expropriation by their larger partners (Lerner and Merges, 1998; Rothaermel, 2001b; Lerner *et al*., 2003).

At the end of our study period in 1997, for example, the old-line pharmaceutical firms marketed and distributed seven of the top-10 selling biotechnology drugs via alliances with new biotechnology firms, even though none of these new drugs were developed by the pharmaceutical companies (Morrison and Giovannetti, 1998). The six new biotechnology drugs accounted for more than two thirds of total revenues ($7.5 billion) accrued by the top-10 selling biotechnology drugs. Often the revenue partition is 50/50 between the large pharmaceutical companies and their biotechnology counterparts (Rothaermel, 2001a). That the biotechnology firms have recently begun to forwardly integrate to capture more value seems to be indicated by the numbers for 2001: the new biotechnology firms distributed six of the top-10 selling biotechnology drugs on their own, again, all of them were developed by new biotechnology firms (Standard & Poor's, 2002). Those six drugs alone captured about 50 percent of the over $13 billion revenues accrued by the top-10 new biotechnology drugs. While these top-performing biotechnology firms seem to withdraw from allying on a case-by-case basis, we do not expect, however, that the technology ventures withdraw from alliances altogether. Rather we expect them to decrease their dependence on an alliance strategy and commensurately reduce their exposure to the risks of opportunism and knowledge expropriation.

Anecdotal evidence from our fieldwork also seems to suggest that technology ventures may gain considerably when they are able to forwardly integrate into the exploitation activities of the product development process. Both Amgen co-founder Rathmann and board member Omenn indicated that Amgen's intended strategy was to originally pursue intensive exploitation collaboration with Johnson & Johnson (J&J) for the new biotechnology products developed by Amgen. However, the collaboration with J&J went sour and ended in a long, drawn-out litigation. As a consequence, Amgen chose to forwardly integrate after its experience with J&J. One could speculate that Amgen became the most successful biotechnology firm to date precisely because it was able to commercialize two blockbuster drugs (reaching over $3 billion in annual sales) on its own (Giovannetti and Morrison, 2000). Amgen's vertical integration strategy into the downstream activities of the value chain seems to resonate with our finding that biotechnology firms tend to first withdraw from exploitation alliances before withdrawing from exploration alliances.

While there may be a liability of unconnectedness (Baum and Oliver, 1992), there also appears to be an offsetting liability of connectedness. Managers of technology ventures appear to balance the trade-off between these liabilities as their resource endowments increase. In fact, our results seem to be in line with the earlier findings that pharmaceutical firms used exploitation alliances with

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biotechnology firms to improve their performance at the expense of the biotechnology firms (Rothaermel, 2001b). In contrast to Powell *et al*. (1996), we find that firms do not opt unconditionally for interdependence, but rather moderate their interdependence with increasing independence through vertical integration on a project-by-project basis. As more internal resources become available to the firms, they become less reliant upon external alliance sources of knowledge and capital.

While many alliances are intended to lead to the creation of new products, given the high degree of uncertainty inherent in the new product development process regardless of industry (Griffin, 1997; Stevens and Burley, 1997), intentions may not readily translate into new products, much less successful ones. Given this high degree of uncertainty surrounding the new product development process in general, it is conceivable that the costs required to identify a suitable alliance partner and to negotiate, manage, and monitor an alliance may negate any potential benefits from the alliance. Aggregated to the firm level, the opportunity costs of an exploration–exploitation alliance strategy in the new product development process can potentially outweigh its benefits. Under these circumstances, firms pursuing an alliance strategy should be no more productive, and perhaps even less productive, than those who pursue a strategy emphasizing internal development.

Our findings also seem to suggest that as technology ventures grow larger, potential partners may need to become increasingly skeptical of the technology ventures' offerings. An expanded resource base allows technology ventures to keep the highest-quality projects for themselves and only offer lower-quality projects to potential alliance partners (Pisano, 1997; Lerner and Merges, 1998). In essence, the tables may turn once a technology venture is able to achieve a threshold size. While technology start-ups may have been penalized initially because the problem of asymmetric information in the market for know-how lowered prices for quality projects, larger more successful technology ventures may be able to take advantage of their position by gaining a price premium for lower-quality projects. This is because lower quality projects crowd out higher-quality projects according to the lemons hypothesis (Akerlof, 1970). In fact, if firm size results in increased legitimacy and attributions of quality to the technology ventures' projects, these firms may be able to gain an additional premium for lower-quality projects.

Some of our secondary findings are also worth highlighting. We found that firms that possess a higher patenting propensity tend to engage in more exploitation alliances and have a greater number of products on the market, although patents were nonsignificant in predicting the firm's products in development. Shan *et al*. (1994) found that alliances predicted a biotechnology firm's patents, while they found no support for a reverse relationship. We presented a more subtle model and found that patents explained alliances, but only a certain kind of alliances—exploitation alliances. In our research setting, it appears that patents are an output of the discovery and development stage of the product development process rather than an input to it (Griliches, 1990).

On the aggregate, we find that biotechnology firms enter into significantly more exploitation alliances than exploration alliances. This finding is in line with Koza and Lewin's (1998) theoretical conjecture that an industry will as a rule be characterized by more exploitation alliances than exploration alliances. Further, our result that exploitation alliances are more frequent than exploration alliances is consistent with Rothaermel's (2001b) finding when studying large established firms rather than newer technology ventures. It appears that exploitation alliances generally exhibit less uncertainty and thus require fewer resources which in turn enables firms to manage more exploitation alliances than exploration alliances. However, one could also speculate that our findings lend support to the notion that exploitation may drive out exploration and that firms could be trapped by their own competencies (Levinthal and March, 1993).

Limitations and future research

While were able to assess each firm's mix of exploration and exploitation alliances, we did not relate specific exploration–exploitation ratios to firm performance. Future research could attempt to specify what mix of exploration and exploitation is best when striving for superior performance, taking the different time horizons for exploration and exploitation learning modes into account. Another path future research could take in analyzing the mix of exploration and exploitation activities would be to determine how much

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of each activity should be pursuit in-house vs. through alliances.

While our arguments highlighted the costs and risks involved of allying, others have emphasized value creation and dyadic processes in interfirm allying (Zajac and Olsen, 1993). Future work should begin by investigating factors that determine the distribution of the rents generated between the different organizations involved in an exploration–exploitation product development process. Subsequently, future work could investigate alliance processes for joint value creation and distribution that may mitigate some of the potential problems new technology ventures can encounter when partnering with established firms.

The results provide support for our research model; however, we must also acknowledge that our focus on biotechnology raises questions about the generalizability of our study beyond this industry. Biotechnology has several unique characteristics, including a long product development and regulatory approval cycle, heavy reliance upon often arcane basic scientific research, and a resource intensive new product development process. Despite these unique characteristics in our sample, we submit that our results might be generalizable beyond the biotechnology industry since basic science and interfirm cooperation in high-technology industries appear to be playing an increasingly important role in the success and failure of individual firms (Hagedoorn, 1993; Dasgupta and David, 1994). For example, recent alliance announcements between the California Fuel Cells Partnership, MIT, and Dupont, which comprises government laboratories, universities, fuel cell ventures, and automobile as well as energy companies, seem to indicate that the fuel cell industry might be pursuing a similar development path as the biotechnology industry. Future research could assess the external validity of our model by testing it in different industry settings.

Another limitation of this study is that we were only able to study surviving alliances. In particular, given the higher degree of uncertainty involved in exploration alliances, one would expect them to exhibit a commensurate higher mortality rate relative to exploitation alliances. However, it is important to note that alliances in the biotechnology industry are characterized by longevity since the product development process can take 15 years or more. For example, Shan *et al*. (1994) found that only 15 percent of the alliances entered since the early 1970s had expired by 1989. Another piece of evidence that only a small number of biotechnology alliances are terminated is provided by Green (1997), who reported that the founding to termination ratio for allying was about 9 : 1 in biotechnology near the end of our study period. Given the low mortality rate of biotechnology alliances, in conjunction with their longevity, we believe that our results are not materially influenced by a potential survivorship bias.

While we were able to find support for an integrated product development path beginning with exploration alliances and concluding with products on the market, we need to emphasize that the performance distribution of commercialized products, in particular in the biotechnology industry, is heavily skewed. One successful blockbuster drug may accrue several billion dollars of revenues for decades, whereas many, if not most drugs, will not be able to cover their research and development cost. Thus, while products on the market are more proximate to firm performance than patenting or products in development used in prior studies (Shan *et al*., 1994; Deeds and Hill, 1996), future research is needed to illuminate the link between newly commercialized products and firm performance.

CONCLUSION

We submit that this paper extends our understanding of the role of strategic alliances in the new product development process by providing a link between alliance participation by technology ventures beginning with discovery and culminating with products on the market. We submit that we have added to the field's understanding of alliances and new product development by developing and testing a more subtle and comprehensive model of the new product development process based on the exploration–exploitation learning framework, transaction cost economics, pecking order hypothesis of optimal capital structure, and information asymmetry in the market for know-how. Our model provides predictions of managerial behavior at different stages of the new product development process including the type of alliances a firm is likely to enter (exploration vs. exploitation), and predicts an overall trend in a firm's tendency to withdraw from alliances as the venture expands. Our results appear to support our proposed product

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development path suggesting that different types of alliances are motivated by different goals, achieve different outcomes, are best employed at different stages of development, and that managers prefer internal resources to external resources when funding promising R&D projects. In conclusion, we do not argue that the technology ventures in our sample see the world as a zero sum game, where there are no synergistic returns to collaboration, but rather that given a particular resource endowment and opportunity set, firms attempt to maximize their product development performance by achieving a balance between the risks and rewards of interfirm cooperation.

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