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Who is My Partner and How Do We Dance? Technological Collaboration and Patenting Speed in US Biotechnology

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In settings where patents and intellectual property provide a strong regime of appropriability, the race to be the first firm to patent a product or a process is a central feature of competition. In this context, we hypothesize that cooperative arrangements that only gain access to external knowledge contribute less to heterogeneity between firms and have a much weaker influence on patenting than alliances that transfer highly firm-specific knowledge, residing in individual and social relationships. We also hypothesize that cooperations between private firms and public organizations accelerate the rate of patenting to a higher degree than cooperations among private firms. We develop and test these ideas on the population of 839 US biotechnology firms between 1973 and 2003. We discuss the importance of our findings on the debate about the value of knowledge access versus knowledge transfer in strategic alliances.

Introduction

In many businesses, intellectual property takes the form of trade secrets and proprietary information. In others, patents and copyrights prevail. The extent to which firms pursue intellectual property in the form of patents appears to be a function of the 'regime of appropriability' – the extent to which firms can appropriate future income streams and thus cover the cost of innovation and still make a profit (Teece, 1987). The ability of biotechnology firms to patent specific molecules and life forms ensures a strong regime of appropriability for most biotechnology firms (Gassmann, Reepmeyer and Zedtwitz, 2008; Pisano, 2006a, 2006b). In this competitive context, the race to patent innovations becomes a crucial aspect of competitive strategy (Amburgey, Dacin and Singh, 1996; Kamien and Schwartz, 1982; Reinganum, 1984).

It is well known that alliances are an important source of knowledge that is essential in this race for patents and knowledge (see for instance Powell, 1987; Powell *et al.*, 2005). However, previous work on strategic alliances in biotechnology industries, including research in the area of organizational learning, has treated all strategic alliances as equivalent (see for example DeCarolis and Deeds, 1999; Powell *et al.*, 2005). Recent advances in the alliance literature (e.g. Grant and Baden-Fuller, 2004) suggest that researchers should make a distinction between knowledge access and knowledge transfer. Hitherto this idea has not been specifically tested; so we take the opportunity to address gaps in the biotechnology alliance literature and provide some empirical exploration of the proposition that accessing knowledge has differing results from transferring and integrating knowledge via alliances. We also take the opportunity to distinguish between different types of partners,

noting the important difference between institutional types of knowledge providers: public (including non-profit) and private (see for example Baum, Calabrese and Silverman, 2000). With regard to the type of cooperation we distinguish between joint research alliances and licensing agreements, and test their effects on a firm's innovative outcome.

To our knowledge prior research has not addressed central questions regarding the relationships between research alliances, licensing agreements and organizational innovativeness. Recent work points to the fact that the categorization between knowledge 'accessing' and 'learning' arrangements might not be as sharp and easily drawn as commonly assumed. For example, some recent studies in the biotechnology sector indicate that a serious amount of knowledge is shared in license agreements in order to advance development (Nightingale and Mahdi, 2006; Pisano, 2006a). Furthermore, recent studies addressing the issue of ambidexterity in cooperations between biotechnology firms and pharmaceutical firms indicate that to some extent exploration takes part in all relationships between the partners, independently from the character of the linkage (e.g. Filiou and Windrum, 2008; Gassmann and Keupp, 2007). Hence, we believe that questions regarding the contingencies and causalities driving knowledge exploration versus exploitation have not received sufficient attention in research so far and that we address an important gap by analysing these issues on the template of cooperation versus licensing.

We also address a gap regarding characteristics of different alliance partner types on the outcome of the cooperation. We are especially interested in the trustworthiness of public versus private alliance partners, e.g. pharmaceutical and biochemical firms versus public universities and research institutes. We assume that private firms are less trustworthy than public organizations, which will influence the outcome of the cooperation.

In the first section of the paper we provide an overview of the mechanisms by which organizations access knowledge and transform it into intellectual property. We then develop three hypotheses linking different types of cooperation to the rate at which biotechnology firms acquire patents. The second half of the paper provides a description of the data and methods used to test our hypotheses, and a presentation and discussion of our results. We end the paper with a brief discussion of implications for our understanding of knowledge access versus knowledge transfer and the role of cooperations in generating patents that often lead to competitive advantage.

Theory

Innovation and the knowledge-based view in strategic management

Theories in strategic management are concerned with explaining and predicting the sources of economic rents for firms. Recently, there has been a stream of research extending the resource-based theory of the firm to constitute a knowledge-based perspective (Sanchez and Heene, 1997; Spender, 1996; Spender and Grant, 1996; Zack, 1999). The emerging knowledge-based view focuses upon knowledge as the strategically most important resource of the firm and devotes itself to the role specific knowledge plays in the development of competitive advantages. According to this theory, heterogeneous knowledge bases are the main determinants of performance differences (Spender, 1996; Spender and Grant, 1996).

Similarly, the study of innovation has traditionally conceptualized the innovation process as the accumulation and recombination of knowledge embodied in science and technology (Kamien and Schwartz, 1982; Rosenberg, 1976; Schumpeter, 1939). Even if there is little agreement on what it means to be innovative, economists and organization theorists both agree on the fact that the only way for an organization to sustain innovation is by constantly upgrading its knowledge base (Acs and Audretsch, 1990; Danielle, 2003; Dosi *et al*., 1988; Iansiti, 1998; Iansiti and Clark, 1994; Spender, 1996). This leads to a challenge for firms to acquire new knowledge outside their boundaries and to build up internal learning capabilities for integrating, transforming and applying knowledge in innovative products and services (Kogut and Zander, 1992, 1996).

Learning from alliances

Recent contributions on analysing cooperations place an emphasis on knowledge- and learning-

related motives, arguing that cooperative strategies are a major means of facilitating inter-organizational learning and gaining access to knowledge outside the firm's boundaries (see for example Badaracco, 1991; Grant and Baden-Fuller, 1995; Hamel, 1991; Kogut, 1998; von Krogh and Roos, 1996; Lyles, 1994; Powell, 1987). Within that literature, a strong argument is made that alliances have advantages over contracts or markets, since drafting contracts governing the sale or licensing of tacit knowledge is difficult due to the non-explicability of the characteristics and performance of that knowledge (Pisano, 1990).

Alliances are considered to be especially fruitful for the development and transfer of tacit knowledge, which forms the basis for a firm's knowledge-based advantage (Badaracco, 1991; Lyles *et al*., 1996; Wathne, Roos and von Krogh, 1996).

Although the predominant emphasis in the literature has been on examining learning-based alliances, the theory and empirics have paid too little attention to those alliances that only access the knowledge of the partner. In the access alliance, each member firm 'accesses its partner's stock of knowledge in order to exploit complementarities, but with the intention of maintaining its distinctive base of specialized knowledge' (Grant and Baden-Fuller, 2004, p. 64). This type of alliance seems to be especially fruitful in industries where products require a broad range of different knowledge types, resulting in the rising cost of knowledge integration within one single firm.

The distinction between learning versus accessing knowledge in alliances is important because it has consequences both for the interaction within the alliance and for the outcome of the alliance. Alliances that are aimed at accessing the partner's knowledge without learning it do not necessarily require intensive interaction between the partners; as a result the routines, procedures and knowledge bases of partners remain differentiated from each other (Grant and Baden-Fuller, 2004, p. 78). The alliance therefore increases the knowledge specialization of partners, whereas the partners' knowledge bases in learning alliances converge over time. There are some limits to the outcome of knowledge-accessing alliances. Prior research indicates that it seems unlikely that the tacit components of knowledge will be transferred given the limited interaction between partners (Lyles *et al*., 1996; Wathne, Roos and von Krogh, 1996). However, we have to take into account that all knowledge resides on a continuum, and that therefore a clear distinction between tacit and explicit components of knowledge might be difficult. Thus, we do not state that tacit knowledge will not be transferred at all in these alliances, but we assume that only small portions of the tacit components of knowledge are accessible due to the limited interaction between partners. We will emphasize this aspect below. Furthermore, there will be limits to the development of the integrative or architectural capabilities (Henderson and Clark, 1990) and to those capabilities required for the effective integration of the acquired knowledge within their own firm (Grant and Baden-Fuller, 2004, p. 79).

In contrast to accessing alliances, the learning alliances explicitly aim at jointly developing, transferring and integrating new knowledge, thereby absorbing some of the partner's valuable and often tacit capabilities (Gambardella, 1995; Gulati, 1995; Powell, Koput and Smith-Doerr, 1996). There are, however, some requirements for the learning to take place (Crossan, Lane and White, 1999; Inkpen and Crossan, 1995; Lyles *et al*., 1996). Wathne, Roos and von Krogh (1996) empirically observe several factors within alliances contributing to the success of the learning relationship. Alliances have to be conceptualized as open learning arenas, where openness can be measured by dialogue: being open is measured by the degree to which the partners' representatives work closely together on a common task and the degree to which the partners' representatives perceive each other to share rather than withhold or shield their knowledge. Another factor influencing the transfer of tacit knowledge is reflected in the characteristics of the channel of interaction within alliances. Learning alliances offer the option of face-to-face interaction, which is a rich medium because of its capacity for immediate feedback and the availability of multiple, interactive cues.

Third, as a consequence of individual interaction, trust and mutual understanding will develop within learning alliances, contributing to knowledge transfer efficiency (Kale, Singh and Perlmutter, 2000; Madhok, 1995; Zaheer, McEvily and Perrone, 1998).

Finally, prior research has pointed to the fact that learning might extend beyond the alliance

itself. When a firm initiates a learning alliance it begins a process of information exchange and interaction that provides a forum for learning, enabling both declarative and procedural knowledge (Cohen and Bacdayan, 1994; Kogut and Zander, 1992, p. 387). The information exchanged typically involves declarative knowledge of facts and propositions. However, ongoing interaction between the partners also produces procedural knowledge, the know-how gained in managing the learning process itself. This experiential learning leads to efficiency gains in converting externally acquired knowledge to internal routines. Firms can build competence by integrating the components of their knowledge base to develop new knowledge over time, a process referred to as 'architectural competence' (Henderson and Cockburn, 1994), 'integrative capabilities' (Lawrence and Lorsch, 1967), 'combinative capabilities' (Kogut and Zander, 1992), 'higher-order capabilities' (Sanchez and Heene, 1997) or 'dynamic capabilities' (Teece, Pisano and Shuen, 1997). By interacting with an alliance, partners' firms might not only acquire new knowledge but also improve their own learning capabilities.

To sum up, we expect significant differences regarding the outcome of cooperation aimed at learning from the partners versus cooperation aimed at accessing the partner's knowledge. Although the distinction between accessing- and learning-based alliances has been made conceptually (Grant and Baden-Fuller, 2004; Hamel, 1991; Hennart, 1988; Mowery, Oxley and Silverman, 1996; Nakamura, Shaver and Yeung, 1990), there are few empirical studies that have shed light on the outcomes of these different types of alliances. Furthermore, no study we are aware of has differentiated alliances by the type of partner and the type of alliance itself. In the following section we will discuss our empirical setting and lay the foundation for our hypothesis.

Hypotheses development

Spectrum of cooperative linkages in the biotechnology industry

Biotechnology is an organizational field composed of a wide variety of organizational forms (Gassmann, Reepmeyer and Zedtwitz, 2008; Hopkins *et al.*, 2007; Pisano, 2006a). The field includes firms such as dedicated biotechnology, traditional pharmaceutical and biochemical companies. The field also includes public organizations such as universities, governmental agencies and research institutes. The true competence of biotechnology firms is applied research devoted to the exploitation of specific scientific discoveries, rather than basic research of the kind conducted in public organizations or the engineering capabilities and marketing system necessary for large-scale production and distribution found in traditional firms (Gambardella, 1995). This disparity in competences and assets has led to a division of labour between public organizations, biotechnology firms and traditional firms. The complementary assets held by each type of organization can then be consolidated through inter-organizational relationships such as strategic alliances (Gambardella, 1995, p. 147).

Strategic alliances within the field of biotechnology have taken a number of different forms including collaborative R&D, licensing agreements and marketing or distribution agreements. We focus our attention on collaborative research agreements and licensing agreements because the knowledge involved in these arrangements can, potentially, lead to patentable intellectual property for biotechnology firms. The knowledge transfer that can occur through marketing and/or distribution agreements may be valuable but is not amenable to patenting. Although biotechnology firms may learn how to distribute products more effectively in a market or how to set royalties efficiently, this is not knowledge which is patentable.

Furthermore, we do not restrict our focus on biotechnology research leading to drug development. Our interest is broader and covers the entire US biotechnology population. While we include drug developments as well as other areas of medicinal biotechnology such as diagnostics we explore alliances covering the development of non-medical applications as well.

The relevance of patents in biotechnology

In this study we link the outcome of a firm's cooperations to its patent productivity. Patents are a critical measure of inventive output for firms especially in knowledge intensive industries (Ahuja, 2000; Almeida and Kogut, 1999; DeCarolis and Deeds, 1999; Rosenkopf and Nerkar,

2001; Sorensen and Stuart, 2000). Whereas there seems to be no or only small effects of patents for securing the returns to innovation in industries such as manufacturing, semiconductor or communication equipment, patents are featured in drugs and medical equipment industries, pharmaceuticals and biotechnology (Cohen, 2005; Cohen, Nelson and Walsh, 2000; Hall, 2003). In the biotechnology industry patents can be considered not only as an indicator of a firm's innovative success but also as a reasonable measure of a firm's innovative capabilities (e.g. DeCarolis and Deeds, 1999; Lerner, 1994; Powell, Koput and Smith-Doerr, 1996). Patents are formalized, codified and explicit manifestations of innovative ideas, products or processes and embody a firm's technological and innovative knowledge. Even more so, patents granted represent successful outcomes of a highly uncertain R&D process (Kamien and Schwartz, 1982). If a biotechnology firm has a history of patenting it has a foundation of (protected) technical knowledge which can enhance the rate of further innovation (Dierickx and Cool, 1989; Hagedoorn, Link and Vonortas, 2000). Moreover, a history of patenting indicates that the firm has acquired procedural knowledge – it has learned how to innovate more efficiently (Powell, Koput and Smith-Doerr, 1996).

In the biotechnology industry patents additionally ensure a high regime of appropriability for a biotechnology firm. In a recent cross-industry survey Blind *et al.* (2006) explored the significance of various protection mechanisms and the motives of patenting. Among firms in all industries biotechnology firms were attaching the greatest importance to patent strategies. With regard to the motives of patenting the first priority was given to the classical knowledge protection motive, to strengthen the incentives for private R&D expenditures. Aside from the knowledge protection motive patents are considered as an important source of revenues for biotechnology firms and provide valuable signals to the capital market and potential investors (Blind *et al.*, 2006, p. 664). Biotechnology firms generate a large portion of their revenues from selling their patented innovations to the pharmaceutical industry, predominantly in the form of out-licensing (Gassmann and Keupp, 2007; Gassmann *et al.*, 2008, p. 35; Pisano, 2006a, 2006b). Thus, in this competitive context, the race to patent innovations becomes a crucial aspect of competitive strategy (Amburgey, Dacin and Singh, 1996).

Characteristics of alliance form and partner type

We build our hypothesis by distinguishing between the form of the alliance and the type of the partners. Our first distinction concentrates on the form of alliance. We focus our attention on two quite distinct forms of alliance, which represent the knowledge-accessing versus knowledge-learning dichotomy that we have discussed earlier, namely collaborative research agreements and licensing agreements. These two forms of alliance differ with regard to the level of interaction. Both research and licensing agreements involve contracting, but joint research necessarily involves interaction between the partners while licensing agreements do not. As a consequence, the type of knowledge that can be transferred between partners varies.

Our first two hypotheses focus upon the differences in the level of interaction in the different types of alliances and the type of knowledge that can be transferred. Licensing agreements are low-interaction relationships; they are a typical example of a knowledge-accessing alliance and so the biotechnology firm has a partner that does not participate in the creation of the knowledge. As a consequence the core competences and assets of the biotechnology firm are not involved in the alliance. Pisano (2006a) has demonstrated that in biotechnology these licensing agreements are typical arm's length contractual arrangements. 'Under the arm's length agreements, there is very little organizational, legal, financial, or operational integration. ... Short term R&D contracts, licensing agreements, and fee-for-service agreements typically take this form' (Pisano, 2006a, p. 108). Licensing agreements between research institutes, pharmaceutical firms and biotechnology firms are an increasingly common strategy in the biotechnology industry. With regard to agreements between pharmaceutical firms and biotechnology firms Gassmann *et al.* (2008, p. 86) observe that out-licensing by pharmaceutical firms (therefore in-licensing for the biotechnology firm) has experienced remarkable growth over the last years. More and more pharmaceutical firms start to license out know-how (e.g. early stage

substances or compounds) of their research department for cost and efficiency reasons, thereby creating chances for biotechnology firms to further develop and integrate the acquired technological know-how with their own research expertise. Often the pharmaceutical company retains a call-back option to license the substance back at later stages of development (Gassmann, Reepmeyer and Zedtwitz, 2008, p. 142).

While some transfer of knowledge will take place in licensing relationships, the explicit learning of the partner's skills and capabilities is not at the core of the agreement. Alternatively, with collaborative research alliances, both partners are involved in the performance of the activity. This type of relationship offers the opportunity to utilize not only the codified knowledge held by the participants but also the tacit knowledge, procedures and routines involved in the creation of new knowledge (Gassmann, Reepmeyer and Zedtwitz, 2008, p. 70). We expect the alliance experience a firm has to enhance its likelihood of successful innovation in two ways. First, we expect the combinative capabilities of the firm to be developed over time as firms show a history of partnering in research (Kogut and Zander, 1992). Second, biotechnology firms with a history of external collaboration will have a better developed internal competence in integrating a wide range of disciplinary knowledge (Henderson and Cockburn, 1994), will have developed greater architectural competence and will therefore have greater success in converting current knowledge into new knowledge. We therefore expect collaborative research alliances in general to enhance the research capabilities of a biotechnology firm and to show a positive influence on their patent rate. However, we need to have a close look at the different kinds of partners, as the effectiveness of knowledge transfer could also be influenced by the partner as well as the type of knowledge transfer arrangement.

Our second distinction therefore differentiates between alliances in the biotechnology industry by the type of partners involved with the biotechnology firm: public research organizations or private firms. These different types of potential partners vary substantially in their scientific foundations and dominant logics (Powell, Koput and Smith-Doerr, 1996; Powell *et al*., 2005). The scientific knowledge base of biotechnology firms is close to that of public research organizations (e.g. both conduct research in the area of molecular biology). Although biotechnology firms share enough scientific knowledge with public research organizations to effectively learn and transfer knowledge, they show a great dissimilarity with regard to their operational knowledge. This is due to their dissimilar dominant logic. Public organizations engaged in basic research are oriented towards the production of knowledge rather than towards the conversion of scientific knowledge into commercial products. Although some public research organizations strive for the commercialization of their research results (i.e. transfer agencies of universities) we do not consider them 'rent seeking', as their primary and only purpose is not to generate rents.

A different picture emerges when we look at the second type of partner. The scientific knowledge of biotechnology firms and pharmaceutical or chemical firms is dissimilar (e.g. molecular biology versus biochemistry). However, the operational knowledge base of biotechnology firms is closer to that of traditional pharmaceutical firms than to that of public research organizations. This is due to the fact that, as entities seeking economic rents, biotechnology firms and traditional pharmaceutical firms have similar dominant logics, both striving for the conversion of scientific knowledge into commercial products (Bettis and Prahalad, 1995; Powell, Koput and Smith-Doerr, 1996).

These distinctions are important for the degree of knowledge that can be transferred within the alliance. Lane and Lubatkin (1998), extending and refining the firm-level concept of absorptive capacity to a dyadic level, argue that the amount of knowledge transfer is largely determined by the relative relationship between the knowledge bases of partners. They therefore expect the similarity in the knowledge bases of partners to influence the amount of knowledge transfer. Organizations will have the greatest potential to learn from organizations with similar basic knowledge but different specialized knowledge (relative absorptive capacity).

With regard to the biotechnology industry, basic knowledge is reflected in the scientific knowledge bases of the organizations, while specialized knowledge is reflected in the operational knowledge bases of the organizations.

Dedicated biotechnology firms therefore share a similar basic knowledge with public research organizations (disciplinary foundations) but differ in terms of their specialized knowledge (commercialization versus basic research). Alternatively, dedicated biotechnology firms and traditional pharmaceutical or chemical firms share specialized knowledge but differ with regard to their basic knowledge base (Gassmann, Reepmeyer and Zedtwitz, 2008; Hopkins *et al.*, 2007; Nightingale, 2000; Pisano, 2006b). As a consequence, we would expect alliances with different types of partners to exhibit different levels of relative absorptive capacity.

To summarize, alliances within the biotechnology field can be classified along two dimensions. The first dimension is the level of interaction between partners and, consequently, the type of knowledge transferred within the relationship (tacit versus codified). The second dimension is the type of partner and, consequently, the relative absorptive capacity of the relationship. We distinguish between the following four forms of alliances in the organizational field of biotechnology (cf. Figure 1).

Our hypotheses look to explain the differing levels of performance between the cells shown in Figure 1. Essentially, we argue that access alliances are less productive in terms of facilitating basic research than collaborative agreements that involve transfer of knowledge. (That is, cells I and II are less productive than cells III and IV.) But we are careful to ensure that we compare like for like. Our first hypothesis thus concentrates on the effects of knowledge-accessing versus knowledge-learning alliances with public organizations (i.e. universities) on the innovative outcome of biotechnology firms. Our second hypothesis addresses the effects of alliances with firms (such as pharmaceutical firms). Both hypotheses thus distinguish between the type of partner and the type of cooperative agreement.

H1: The effect on the patent rate of prior research alliances with public organizations is greater than the effect on the patent rate of prior licensing agreements with public organizations.

H2: The effect on the patent rate of prior research alliances with firms is greater than the effect on the patent rate of prior licensing agreements with firms.

Our third hypothesis specifically incorporates the type of partner. We argued above that relationships with public organizations should produce higher relative absorptive capacity for biotechnology firms than relationships with pharmaceutical or chemical firms. This alone suggests that collaborative research with public organizations should enhance research productivity more than collaborative research with other firms. In addition, we propose that the difference in dominant logics between public organizations and firms will influence the quality of the interactions between partners and will influence the amount of trust between partners. Wathne, Roos and von Krogh (1996) argue that the overall perceived openness

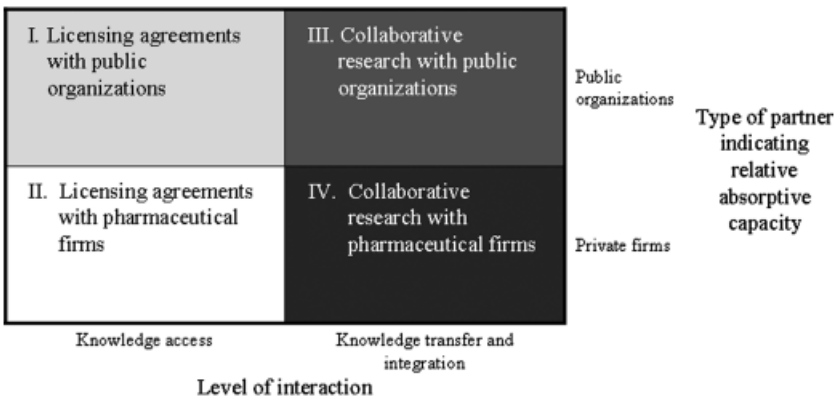

Figure 1. Types of alliances in the biotechnology industry

Note: Hypothesis 1 compares cells I and III; Hypothesis 2 compares cells II and IV; Hypothesis 3 compares cells III and IV.

of dialogue and the degree to which the partner representatives perceive that the others withhold or shield their knowledge affects knowledge transfer. Other research has shown that trust contributes to greater knowledge exchange between alliance partners (e.g. Kale, Singh and Perlmutter, 2000) and has positive effects on the efficiency of a research alliance because it facilitates the learning process and the transfer of knowledge itself (Madhok, 1995).

Relationships with firms involve a risk of knowledge appropriation and the loss of valuable intellectual property: indeed much of the academic and managerial literature on organizational learning is devoted to discussion of the need to protect intellectual property when engaging in strategic alliances (Liebeskind, 1996). Turning to the relationship between biotechnology and pharmaceutical firms several aspects need to be considered. As entities seeking economic rents, biotechnology and pharmaceutical firms have similar dominant logics, both seeking the conversion of scientific knowledge into commercial products (see Pisano, 2006a; Roijakkers and Hagedoorn, 2006; Rothaermel and Deeds, 2004). Their similar dominant logic does not inhibit the evolution of trust between pharmaceutical and biochemical firms. However, it makes pharmaceutical firms less trustworthy partners than public organizations (Hoang and Rothaermel, 2005). This might explain why recent large-scale studies have observed an increase in the amount of explicitly formalized (e.g. contractual) research relationships between biotechnology and pharmaceutical firms (see Roijakkers and Hagedoorn, 2006; Rothaermel and Deeds, 2004).

On the other side, public organizations are not rent-seeking organizations and are therefore more oriented towards the production of basic discovery than the conversion of scientific knowledge into commercial products. While this may not make public sector partners more trustworthy within their own sector, such differences in the uses of the knowledge created in an alliance are likely to make them trustworthy partners for biotechnology firms (Powell, Koput and Smith-Doerr, 1996). Even in those rare cases where public organizations such as universities are 'revenue-oriented' (i.e. seeking to generate research funding from public sources or on some occasions generating revenues from out-licensing patented innovation through their 'transfer institutes'), we do not consider them 'rent-seeking', as their primary and only purpose is not to generate rents. Public organizations have charters that are aiming at public goods and public goals (set by governments); there are no shareholders in these organizations. This does not restrict them from generating financial revenues, but it is not their primary goal.

Summing up, we propose that relationships with public organizations will involve a greater perceived openness of dialogue and less of a perception that the partner is withholding or shielding knowledge. We therefore expect research alliances with public organizations (e.g. universities) to show a higher influence on the patent rate than research alliances between pharmaceutical and biochemical firms. Our third hypothesis therefore compares cell III with cell IV in Figure 1.

> *H3*: The effect on the patent rate of prior research alliances with public organizations will be greater than the effect on the patent rate of prior research alliances with firms.

Data and methods

Data

The longitudinal data set used in the study consists of the complete US population of 839 biotechnology firms founded during the period 1973–1999. The significance of the beginning date was the major Cohen–Boyer breakthrough in 1973. We used two primary sources to compile the sample. The first was the BIOSCAN database published by Oryx Press. The second source was the US Companies Database compiled by the North Carolina Biotechnology Center (now Bioworld). We purged the consolidated list of companies of all firms which were founded before 1973, which were not US firms or which were non-independent entities (subsidiaries, divisions and joint ventures) to arrive at 839 companies.

These data and other sources were used to construct an event history for each company. Event histories are data structures that include information on the number, timing and sequence of the events that are being examined. Each firm's history began at the time of its incorporation or qualification to do business and ended at the time

of an event or at the end of the month, whichever came first. The organization's second spell started on the following day and ended at the time of an event or the end of the month. This pattern continued until the firm exited (through failure or acquisition) or until the end of the observation period, in which case spells were coded as 'right censored'. This procedure allowed time-varying covariates to be updated throughout the firm's history at monthly intervals.

A wide variety of sources were used to augment the information in our two primary sources. We examined the legal archives on the LexisNexis service to obtain exact dates of incorporation or qualification to do business. A search of the news archives on LexisNexis (including specialized outlets such as Biotechnology News Watch) was used to identify dates of events. Similarly, the online archives of Recombinant Capital provided supplemental information on strategic alliances. Information from the US Patent and Trademark Office was the primary source for the assignment of patents. In those cases where only the month and year of an alliance could be determined, the day was set at the midpoint of the month to minimize errors in timing.

Dependent variable

The dependent variable is the patent rate $\lambda(t)$. The rate is defined as

$$\lambda(t) = \lim[q(t, t + \Delta t)/\Delta t] \;\; \Delta t \to 0$$

where q is the discrete probability of the firm filing a patent between t and $t+\Delta t$, conditional on the history of the process up to time t. This rate summarizes the information on the intervals of time between successive events, with higher values of the rate corresponding to shorter times between events (higher patenting speed) and vice versa. In using patent data we follow the research efforts of several other scholars who have used patents as a measure of innovative success of firms (Albert *et al.*, 1991; Dutta and Weiss, 1997; Engelsman and van Raan, 1994; Henderson and Cockburn, 1994; Jaffe, Trajtenberg and Henderson, 1993; Narin, Noma and Perry, 1987; Rosenkopf and Nerkar, 2001). We have to acknowledge that there are a number of potential limitations of using patent data. First, patents are a partial measure of the production of organization knowledge: they may capture codified knowledge flows but not tacit knowledge (such as that embedded in organizational routines). Our study therefore captures innovation and knowledge exchanges of articulated technological knowledge. However, empirical findings suggest that codified knowledge flows (represented by patents) and tacit knowledge flows are closely linked and complementary (Mowery, Oxley and Silverman, 1996).

Another potential drawback in the use of patent data is that patenting is itself a strategic choice and hence all technological innovations may not be patented. However, the nature of competition in the biotechnology industry encourages fast patenting of innovations. Patents form the intellectual capital of this industry (Shan and Song, 1997). In this context, the race to patent innovations becomes a crucial aspect of competitive strategy: given that patents are granted to the first to invent the idea, running second provides little benefit.

We also want to emphasize that our data set consists of the entire US biotechnology population. This means that while we include drug developments as well as other areas of medicinal biotechnology such as diagnostics, we explore non-medical applications such as the development of platform technologies and tools as well. This has the consequence that our data comprehends patented innovations that do not involve the development of a new chemical entity (NCE). Thus, we are not concerned with innovation in terms of approval of new chemicals, but we are looking at the broader field of innovation in general.

Independent variables

Our primary independent variables are cumulative counts of prior research and in-licensing agreements between US biotechnology firms and US or non-US partners. We code the initiation date of the agreements, but we do not measure the duration of these agreements. Given our data structure, unfortunately, we do not have information on the termination dates of research alliances and licensing agreements to generate time spells of agreement durations. All agreements in the database were coded to include information on the type of the agreement and on the type of partner. For this paper we distinguished two types of agreements, research

alliances and in-licensing agreements. We then constructed the cumulative count of prior research alliances with public organizations engaged in basic research (universities and research institutes) and with pharmaceutical or biochemical firms. Similarly, we constructed the cumulative number of prior in-licensing agreements with public organizations engaged in basic research and with pharmaceutical or biochemical firms. We did not treat public and private universities separately, but included both types of universities in the data analysis. The reason for treating them equally is that they do not differ fundamentally in aspects decisive for our research question. Whether public or private, they are both universities and therefore institutions with public goals and public charters and similar constraints. With regard to the licensing agreements we focus on in-licensing, a strategy where a biotechnology firm signs a contract with a third party to gain access to usage rights for technological know-how. From our own experience in biotechnology and from other research we know that in-licensing agreements are typical 'arm's length' relationships where mutual learning is not intended.

Control variables

Two types of control variables were used in the analysis: attributes of the environment and attributes of individual firms. Although the bulk of strategic management theory emphasizes the primacy of strategic choice, much of the recent work on innovation has emphasized the importance of organizational context. In this paper, we examine the impact of organizational attributes and choices on the rate at which biotechnology firms acquire patents, while attempting to control for the effects of context.

Population level controls

Contextual variables included population density, corporate patents granted and counts of alliances by other firms.

Population density. In many instances, the number of firms has been found to be positively related to the rate of innovation and patenting (Reinganum, 1984; Sah and Stiglitz, 1987). The argument is that a larger number of competitors increases the intensity of rivalry in such a way that firms accelerate their development programmes. Population density was defined as the total number of biotechnology firms in existence at the beginning of a calendar year. The density variable was adjusted to reflect the disappearance of firms through failure, acquisition or merger.

Total corporate patents granted in the population. The annual number of all corporate patents granted in the population was used to measure cumulative patent activity in the biotechnology population. We followed the classification of the US Patent and Trademark Office and included all biotechnology patents (predominantly US patent classes 424 and 514).

Total number of alliances in the population. Annual counts of strategic alliances among all biotechnology firms in the population were used to capture competitive rivalry produced by cooperative strategies. These counts were adjusted for each firm to remove their alliances and patents.

Firm level controls

The second set of control variables measured attributes of the firms themselves. Much of the decision and game theoretic work in economics assumes that firms are identical, engage in one project at a time, and do not transfer knowledge from one patent race to the next (Kamien and Schwartz, 1982, pp. 189–193). Even the most cursory examination of biotechnology questions the validity of these assumptions. We do not assume identical firms: our primary interest is precisely in the ways in which firms vary in their ability to acquire intellectual property. However, not all differences between firms are central to our analyses, some being merely potential confounds.

Firm age. The first variable was firm age, measured as the number of days since the founding or qualification of the firm.

Prior patents. The second was the cumulative number of prior patents of the firm. This variable

was updated whenever a patent was granted. Kamien and Schwartz (1982) assert that the effect of technical uncertainty in the R&D process is to make the effort required for successful completion an unknown. In this situation, successful innovation and the time of its occurrence are probabilistic. However, they argue that the probability of successful completion at any time is an increasing function of cumulative effort at that time. Cumulative effort may increase the probability of successful innovation but an accumulation of successful outcomes is even more likely to do so. If a firm has a history of successful patenting it will have a foundation of (protected) technical knowledge which can enhance the rate of further innovation. Moreover, a history of successful patenting indicates that the firm has acquired procedural knowledge – it has learned how to innovate more efficiently.

Absorptive capacity. The ability to recognize, acquire and exploit new knowledge (i.e. the concept of absorptive capacity) will influence a biotechnology firm's ability to convert knowledge into patents. Our measure of absorptive capacity was the number of research domains within which the firm participated. Six research domains were used to categorize the firms: diagnostics, therapeutics, agricultural, veterinary, food/fermentation and other. The BIOSCAN database and information from the North Carolina Biotechnology Center were used to classify each firm. The number of research domains in which firms were active was a simple count.

In conceptualizing the breadth of a firm's knowledge base as a proxy for its absorptive capacity we follow prior research that has conceptualized absorptive capacity as a knowledge base – more specifically, as the extent of prior knowledge in the firm (Ahuja and Katila, 2001; Kim, 1998; Mowery, Oxley and Silverman, 1996) – and utilized proxies such as R&D intensity (Meeus, Oerlemans and Hage, 2001; Mowery, Oxley and Silverman, 1996; Tsai, 2001) and patents (Ahuja and Katila, 2001; Mowery, Oxley and Silverman, 1996). We refine that approach by linking characteristics of a firm's knowledge base to the concept of absorptive capacity. Especially the breadth and complexity of a biotechnology firm's scientific knowledge base – as reflected in the number of different research domains it is active in – serves as our indicator of absorptive capacity (see similar Galunic and Rodan, 1998; Van den Bosch, Volberda and De Boer, 1999). In other studies absorptive capacity has been related to the scope of a firm's knowledge base, such as the breadth of its product-market knowledge or the breadth of its capabilities in general (Ahuja and Katila, 2001; Barkema and Vermeulen, 1998; Isobe, Makino and Montgomery, 2000; Kim and Kogut, 1996). Furthermore, our concept of absorptive capacity is also linked to organizational learning (Autio, Sapienza and Almeida, 2000; Barkema and Vermeulen, 1998). Especially with regard to knowledge and innovation intensive firms innovation is best supported by an absorptive capacity based on a broad range of loosely related knowledge domains that help to further increase that breadth (Van den Bosch, Volberda and De Boer, 1999).

Access to financial resources. The remaining firm-level control variables are the public/private status of the firm and the cumulative number of prior private placements of equity, two indicators of access to financial capital. Many scholars of innovation have argued that R&D is difficult to finance externally, yet R&D can require substantial capital. One implication of a financing constraint is that firms with greater access to capital can engage in research at a greater pace.

Model

Since the occurrence of patents over time for a firm represents a series of repeated events, event history analysis is a very useful analytic technique. The event series was modelled as a stochastic point process (Amburgey, 1986). The patent rate $\lambda(t)$ was specified as an exponential function of the independent variables and a set of parameters capturing the effects of the variables on the patenting rate, such as

$$\lambda(t) = \exp(\beta X_t)$$

The use of an exponential baseline model such as this is common in event history analyses. Since we included the age of the firm as an explicitly measured covariate we did not use a Weibull specification to add a second model parameter for monotonic time dependence. Parameters were estimated using maximum likelihood with the STATA program. The estimation procedure clus-

tered observations by firms to reduce the impact of unobserved firm-specific effects (White, 1982). The significance levels of the parameters were evaluated by examination of t-ratios, whereas the goodness-of-fit of the different models compared to the constant term only model was evaluated by examination of Wald statistics. The Wald statistics describe the improvement in fit between hierarchically nested models and follow a chi-squared distribution with degrees of freedom equal to the difference in the number of parameters of the two models. We used two models to evaluate our hypotheses. The first model included only control variables and constitutes a baseline model. The second model included the control variables and the primary variables. This model was used to evaluate the hypotheses. In comparing the full model with the model that only contains the control variables, we used the likelihood ratio statistic. Our use of the robust variance estimator (clustering multiple observations of the same firm) potentially invalidates the use of the likelihood ratio test, so some caution should be used in the comparison of these two nested models.

Results

Table 1 provides means and standard deviations for the variables in our models as well as a correlation matrix. All of the variables used in the model have moderate inter-correlations except the number of firms and the total number of strategic alliances, which are highly correlated. Given the large number of patents, multicollinearity among covariates does not seem to be a problem. Table 2 provides the results of our event-history analysis. Model 1 provides parameter estimates for the control variables only, while Model 2 provides parameter estimates for control variables and the independent variables used to test our hypotheses. The parameter estimates in Model 1 indicate that all of the control variables, except the number of firms and prior private placements of equity, have a significant effect on the rate at which biotechnology firms generate patents. Of the six control variables with significant effects, five of the variables accelerate the patent rate; only the total number of alliances in the population depresses the patent rate. The likelihood ratio test for Model 1 indicates that it is a significant improvement over the random-effects baseline model.

The parameter estimates provided in Model 2 indicate that the control variables continue to exhibit a similar pattern although some effects are attenuated and the number of research domains no longer affects the patent rate. Of the four variables of interest, one has a significant effect on the patent rate and two have a marginally significant effect. The number of prior licensing agreements with public organizations engaged in basic research does not have a significant effect on the patent rate. The number of prior licensing agreements with pharmaceutical or biochemical firms has a negative effect on the patent rate, although the parameter estimate is only significant at the 0.10 level. The estimate for the effect of prior research alliances with public organizations engaged in basic research is positive and statistically significant. The estimate for

Table 1. Descriptive statistics

Variables	Mean	SD	2	3	4	5	6	7	8	9	10	11	12
1. Number of firms	480.1	150.5	0.93	0.70	0.42	0.20	0.21	0.17	−0.05	0.15	0.09	0.13	0.10
2. Total strategic alliances	346.2	149.8		0.71	0.39	0.19	0.21	0.17	−0.05	0.15	0.09	0.12	0.10
3. Total corporate patents	184.3	135.2			0.29	0.14	0.14	0.14	−0.05	0.10	0.06	0.08	0.06
4. Age	2190.5	1583.9				0.24	0.25	0.34	0.07	0.14	0.17	0.08	0.13
5. Public firm	0.2258	0.4181					0.52	0.34	0.21	0.23	0.32	0.22	0.22
6. Prior private placements	0.7274	1.697						0.43	0.28	0.27	0.45	0.27	0.36
7. Prior patents	1.613	5.807							0.14	0.16	0.41	0.21	0.31
8. Number of research domains	1.949	1.006								0.19	0.18	0.11	0.11
9. Prior research alliances – public	0.2147	0.8816									0.25	0.27	0.19
10. Prior research alliances – firms	0.2334	1.174										0.18	0.45
11. Prior patent licences – public	0.1152	0.5828											0.22
12. Prior patent licences – firms	0.0757	0.4985											

All correlations significant at $p < 0.05$. Based on 95,342 spells.

Table 2. The effects of environmental and organizational variables on the patent rate

Variables	Model 1	Model 2
Number of firms	0.0002	0.000
	(0.0006)	(0.0006)
Total strategic alliances	−0.002**	−0.002**
	(0.0006)	(0.0006)
Total corporate patents	0.004**	0.004**
	(0.0004)	(0.0004)
Age	0.0001**	0.00009*
	(0.00004)	(0.00004)
Public firm	1.216**	1.169**
	(0.167)	(0.173)
Prior private placements	0.018	0.022
	(0.020)	(0.022)
Prior patents	0.050**	0.049**
	(0.004)	(0.005)
Number of research domains	0.101**	0.057
	(0.036)	(0.043)
Prior research alliances with public org.		**0.083****
		(0.039)
Prior research alliances with firms		**0.036***
		(0.020)
Prior licensing agreements with public org.		**0.003**
		(0.037)
Prior licensing agreements with firms		**−0.053***
		(0.031)
Number of events	2432	2432
Chi-squared	1277.73	1456.82
Degrees of freedom	8	12
p value	$p<0.001$	$p<0.001$

**$p<0.05$; *$p<0.10$.

the effect of prior research alliances with pharmaceutical or biochemical firms is positive but only statistically significant at the 0.10 level.

We evaluate our hypotheses by comparing the parameter estimates of different variables. We do this by conducting a difference-of-means test for the relevant coefficients. In Hypothesis 1 we proposed that the effect of prior research alliances with public organizations would have a greater effect on the patent rate than prior licensing agreements. The coefficients are significantly different from one another and the difference is in the proposed direction, thus providing support for Hypothesis 1. We made an equivalent argument for research alliances and licensing with pharmaceutical and chemical firms in Hypothesis 2. Again, the coefficients are significantly different from one another and the difference is in the proposed direction, thus providing support for Hypothesis 2. Finally, Hypothesis 3 was that research alliances with public organizations engaged in basic research would have a greater effect on the patent rate than prior research alliances with pharmaceutical or biochemical firms. The relevant coefficients are significantly different from each other and in the proposed direction, which provides support for Hypothesis 3.

Discussion

Most experts agree that the acquisition of intellectual property is an important component of competitive strategy in innovative industries. This research indicates that the strategic actions of biotechnology firms have an important impact on their ability to generate patentable intellectual property. Our results clearly indicate that an alliance that is aimed at purchasing codified intellectual property (e.g. in-licensing patents) is not, by itself, an effective means of generating new knowledge. First, the purchase of codified knowledge is not likely to provide access to the tacit knowledge required for successful integration with the firm's current knowledge base; the integration of the knowledge (development of linkages) is therefore problematic (Grant and Baden-Fuller, 2004). Second, since some portion of the knowledge may be embedded in specific routines within the selling organization, the utilization of the acquired knowledge by the buying firm may also require the transfer of routines as well as the codified knowledge. These organizational routines may be codified (and thus not tacit knowledge) but will not accompany the patent itself (Pisano, 1994, 2006a, 2006b). Acquiring explicit knowledge therefore does not contribute to the development of the internal capabilities of the firm necessary to recombine prior and new knowledge in a way that leads to innovation (Kogut and Zander, 1996).

For knowledge that is to be accessed from another private firm the motivation for the purchase is often to 'catch up' with rivals and try to overtake them. Here, there is considerable danger that the rival is so far ahead that catch-up is not possible. Our data confirm this fact. The influence from knowledge access alliances with private firms on the patent rate is significantly negative. This suggests that accessing knowledge and competences from external rival private

sources will be largely a waste of effort and may even hinder or delay the development of the internal innovative capabilities of the firm. The strategic capabilities of the firm take time and practice to be developed (Henderson, 1996, p. 370). Huber (1991) as well as Cohen and Levinthal (1990) argue that firms not actively applying knowledge stock do not receive the necessary feedback to build up and develop their capabilities over time (Dierickx and Cool, 1989, p. 1508). Critical capabilities will not be developed when critical knowledge is sourced externally. We assume that licensing external knowledge will not enhance a biotechnology firm's ability to generate new knowledge in the form of patents.

From a more general point of view our findings reconfirm the basic argument of the resource- and knowledge-based theories of the firm that any asset (including knowledge) that can be purchased in a market is not likely to provide sustainable competitive advantage (Barney, 1986, 1991). Our analyses strongly support this argument since prior licensing of patents does not enhance patenting among biotechnology firms. Only collaboration in the research process provides access to the tacit knowledge which can, potentially, provide an advantage.

This is not to say that purchased knowledge plays no role at all, but merely that licensed patents can act only as enabling knowledge. Take for example the Cohen–Boyer patent for the use of plasmids in recombining DNA. Any biotechnology firm involved in recombinant DNA had to license the patent to operate; it was a necessary or enabling condition. However, the purchase of the patent rights would not be a sufficient condition for the generation of new knowledge.

Of equal importance is our finding that research collaboration does enhance the development of patentable intellectual property. Although the most substantial effect in our research is the public/private status of the firm, research collaborations are an important way to stimulate research output. The knowledge-based view of the firm suggests that the acquisition of tacit and procedural knowledge is an important element in gaining competitive advantage. Research collaborations provide a mechanism for this type of knowledge transfer that is not possible with arms' length relationships such as licensing. Our analysis therefore indicates that research collaborations can provide competitive advantage in patenting.

We argue that this is due to two effects. The first effect refers to the development of combinative capabilities over time as firms show a history of partnering, enhancing a firm's ability to combine externally developed knowledge with existing internal knowledge to generate new innovative outcomes. Additionally, biotechnology firms with a history of external collaboration will have developed architectural competence more successfully to integrate a wide range of knowledge components, e.g. knowledge in different scientific disciplines. Our findings are in line with recent research indicating that external collaboration helps biotechnology firms to build internal capabilities for innovation (Grant and Baden-Fuller, 2004; Owen-Smith and Powell, 2004; Rothaermel and Deeds, 2004).

Our research suggests, however, that not all collaborative research is equally effective. The organizational learning literature suggests that the combination of dissimilar, non-redundant knowledge is more likely to generate innovation (Dussauge, Garette and Mitchell, 2000). Our analyses are supportive of this notion, and highlight the importance of relative absorptive capacity (Lane and Lubatkin, 1998). Much of the prior work on absorptive capacity conceptualized it as a characteristic of an organization. Our research suggests that absorptive capacity is a dyadic phenomenon.

This research extends prior research in several ways. Much of the previous work on strategic alliances in biotechnology industries, including research in the area of organizational learning, has treated all strategic alliances as equivalent (see for example DeCarolis and Deeds, 1999). Moreover, even research which has distinguished between types of alliances has not distinguished between types of partners (see for example Powell, Koput and Smith-Doerr, 1996). Our research suggests that it is crucial not only to distinguish between different forms of alliance when researching organizational learning but also to distinguish between different types of partners (see for example Baum, Calabrese and Silverman, 2000). Firms therefore have to make deliberate decisions about which partner type to add to their alliance portfolios.

In addition, our research contributes to the distinction between knowledge-accessing and

knowledge-learning alliances that has received attention in recent research (e.g. Grant and Baden-Fuller, 2004). Our findings shed light on the consequences of engaging in alliances that aim purely at accessing the knowledge of partners. While these alliances might be useful in acquiring valuable knowledge components (i.e. technologies), they restrain firms from developing their own innovative capabilities. Accessing knowledge from external partners therefore shows consequences that are quite distinct from jointly developing knowledge and capabilities. This aspect has not received sufficient attention in prior research on the consequences of in-licensing of knowledge (Gassmann *et al*., 2008). Our findings clearly point to the necessity of future research in this field.

Finally, there are some implications for public policy that can be deduced from our findings. Our analysis suggests that the American approach of a pluralist and contextual technology policy (Giesecke, 2000, p. 214) has been quite successful in connecting new scientific knowledge from research institutions to industrial demand (Whittington, Owen-Smith and Powell, 2009). The US public policy initiatives in biotechnology to develop and support regional clusters around universities have followed examples from other innovation systems in for example Japan, the UK or France (Kaiser and Prange, 2004; Lehrer and Asakawa, 2004; Löfsten and Lindelöf, 2002). This approach seems to foster the development of a functioning system of innovation at least regarding the linkages of universities and high-technology firms (such as biotechnology firms). However, analysing the contingencies of network linkages between public as well as private actors with high-technology firms might be an important area for future research.

Limitations and implications for future research

Several limitations of this research should be taken into account when interpreting our findings. While our research sheds light on innovative processes in the biotechnology industry in general, and their results in terms of patents, we have to take into consideration that a more refined view of the different sectors in this industry might be promising. For example, we have to acknowledge that at present there is an unclear picture regarding the impact biotechnological research has for the overall scientific development in health care (i.e. approval of NCE). While some researchers raise concerns regarding the merits of the so-called 'biotech revolution' in health care (see Hopkins *et al*., 2007; Nightingale, 2000; Pisano, 2006a), we believe in the future potential of this specific industry segment. There seems to be a consensus that biotechnological research 'has helped the creation of a new industrial sector and has enabled a massive restructuring of the industrial organization of target identification and validation, drug discovery and the very early stages of development' (Hopkins *et al*., 2007, p. 583). Similarly, Nightingale (2000) observes that the pharmaceutical industry is to an increasing degree dependent on biotechnological innovations (i.e. in the form of patents). Given that the underlying characteristics and nature of the innovation process in that industry has changed, cooperation with biotechnology firms can significantly speed up drug development in pharmaceutical firms (see Pisano, 2006a). However, considering that our research covers the entire biotechnology population (and not only those firms concentrating on drug development) our results only partially contribute to this ongoing debate.

Second, there might be some concerns regarding our dependent construct, the patent rate. Some recent research has pointed to the observation that patents only provide a limited regime of appropriability for biotechnology firms, as pharmaceutical firms appropriate a significant share of the value of the biotech innovation (see Pisano, 2006a). This is due to a pharmaceutical firm's control over co-specialized assets to produce the drug and bring the drug to market. While we acknowledge this fact, we believe that patents are of strategic value for a biotechnology firm to secure a steady revenue stream, either in the form of out-licensing innovation to the pharmaceutical industry or from milestone payments received in development agreements (Gassmann and Keupp, 2007; Gassmann *et al*., 2008, p. 35; Hopkins *et al*., 2007, p. 581). However, considering that our research covers the entire biotechnology population (and not only biotechnology–pharma alliances aimed at drug development) our results only partially contribute to this ongoing debate.

We also believe that it would be valuable to have a more refined data set that would allow us

– for example – to distinguish between different phases in the scientific discovery process. We could then distinguish a biotechnology firm's role in basic research, applied research, product development and testing, for example.

From a method point of view, our research uses the difference in basic dominant logic between public organizations and private rent-seeking firms and basic differences in scientific disciplines to measure relative absorptive capacity. Clearly, a more refined approach would be preferable. For example, pharmaceutical and biochemical firms vary greatly in the number and type of scientific disciplines involved in their businesses. In addition, our measure of absorptive capacity focused only upon the breadth of knowledge domains. It is possible for example that the prior patents held by a biotechnology firm are also an indicator of absorptive capacity.

Our research suggests several implications for future development. One area is the possible moderating effects of absorptive capacity on the relationship between cooperative activities and the generation of new, codifiable knowledge. Our study suggests that only research relationships enhance innovativeness and that research relationships with public organizations are more efficacious. However, it is possible that biotechnology firms with a high level of absorptive capacity can utilize purchased knowledge to generate innovation while firms with a lower level of absorptive capacity cannot.

Another avenue would be to extend the research to include the commercial outcomes associated with the patents generated by biotechnology firms. The resource- and knowledge-based theories of the firm are, at their foundation, concerned with competitive advantage and the generation of economic rents. By treating all patents as equivalent, we may be missing important economic outcomes associated with different patents. Extending our research to include measures of, for example, success in generating commercially viable products would be an important contribution in future research.

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