Cluster or network effects? Analyzing innovation drivers in biotech

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ABSTRACT

This paper examines the consequences of local versus international linkages for the innovative success of German biotechnology firms. The findings of our longitudinal event history analysis indicate that the most valuable innovation drivers are international research alliances and centrality within the international research network. Surprisingly, we do not find any local cluster effects on the patent rate: neither the density of a local cluster, nor its diversity or age is of significance. Our results shed new light on the relevance of international linkages for knowledge-intensive firms.

1. INTRODUCTION

In this paper we analyze drivers of innovative success for start-ups in knowledge intensive industries. Given the fundamental importance of knowledge for innovative success, we argue that firms who access and exploit external knowledge will increase their innovation speed. More specifically, we state that firms who are connected to external knowledge sources will develop their innovative capabilities faster than unconnected firms, which eventually leads to an increase in their rate of patenting. We draw upon the knowledge based theory of the firm and on recent streams in international entrepreneurship suggesting that new knowledge is created by the combination of new components or by new combinations of existing components. We posit that especially the incorporation of knowledge from a different national context, e.g. from international sources, increases the opportunity set of new knowledge components that can be utilized.

2. THEORY

2.1 Innovation and the recombination of knowledge

The idea that innovation arises from the recombination of existing and new knowledge is well established within the knowledge based view of the firm (Spender and Grant, 1996; McEvily and Chakravarthy, 2002; Grant, 1996). More specifically, innovation is seen as an outcome of a process involving the development, diffusion and application of knowledge embedded within particular social and institutional contexts (McLoughlin, 1999; Robertson et al., 2003; Van de Ven, 1986). As a consequence the only way for an organization to sustain its innovative competencies is by constantly upgrading its knowledge base (Acs and Audretsch, 1990; Dosi et al., 1988; Iansiti and Clark, 1994; Spender, 1996; March, 1991). Several studies have emphasized the critical function of merging knowledge from external and internal sources for innovation (DeCarolis and Deeds, 1999; Mansfield, 1988; Peck, 1962; Rosenberg and Steinmuller, 1988; Saxenian, 1990; Galunic and Rodan 1998; Kogut and Zander, 1992;

Baptista 1998). However, no study so far has analyzed the influence of different sources of external knowledge on the innovative success of firms.

2.2 External linkages, innovative capabilities and patenting rate

In this paper we hypothesize that accessing external knowledge will foster the development of a firm's innovative capabilities, which in turn will increase its innovation speed in the form of patents. Prior research has demonstrated that the development of a firms innovative capabilities can be enhanced by its ability to access external flows of knowledge (Bontis and Crossan, 1999; DeCarolis and Deeds, 1999). By accessing external knowledge firms can build capabilities in integrating and recombining the various components of their knowledge stock to develop new knowledge and innovations (Kogut and Zander, 1992; Henderson and Cockburn 1994; Teece et al., 1997). However, while it seems obvious that a firms internal innovative capabilities correspond with the output of the innovation process, i.e. new products or patentable innovations, we want to discuss the mechanisms translating external knowledge into patenting speed. There are several mechanisms linking outside sources of knowledge to the speed of the innovation process (March and Simon, 1958: 188; von Hippel, 1988).

The first and most important one lies in the concept of absorptive capacity, a firms ability "to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal 1990: 128). Absorptive capacity enables firms to better recognize and access external technological developments and external information, evaluate them and integrate them faster into its own innovation process. Absorptive capacity speeds up the innovation process by enabling the organization to make novel linkages between prior and new knowledge and to better incorporate external knowledge into new products and processes amendable to patenting (Cohen and Levinthal 1990: 131). Turning to the question of how absorptive capacity can be developed, Cohen and Levinthal (1990) point to the fact that the level of absorptive capacity of a firm is a function of prior knowledge of the firm, either acquired externally or developed internally through R&D efforts. Accessing external knowledge will therefore contribute to the development of absorptive capacity, which in turn will foster the innovation process as described above.

There are additional mechanisms for external knowledge linkages to accelerate the innovation process. Knowledge from external linkages can increase a firm’s openness to its environment and stimulate internal innovativeness (Haagedorn 1993; Terpstra and Simonin 1993). In fact, Teece has argued that “to be successful, innovating organizations must form linkages upstream and downstream, lateral and horizontal” (1992: 22). External linkages raise a firms awareness of where useful complementary expertise resides outside the organization. This sort of knowledge can be knowledge of who knows what, who can help with what problem, or who can exploit new information (Cohen and Levinthal: 1990). External linkages will permit the firm to better understand and therefore faster evaluate the importance of external technological advances that provide signals as to the eventual merit of its own technological development efforts (Deeds et al. 1999). The firm is therefore getting valuable feedback to evaluate its own technological position and the potentials of its own innovative efforts. Such feedback will increase the firm´s agility to adjust its own research agenda, and concentrate on those research projects that are most successful and eliminate those that are risky.

External linkages thus provide firms with background knowledge that would permit them to exploit rapidly useful scientific and technological knowledge through their own innovations or to be able to respond more quickly to competitors moves, in both cases improving their innovation speed. Early on and consistent with these arguments, von Hippel (1988) has pointed to the importance of close network relationships for innovation. Following this reasoning, Deeds and Hill (1996) and Shan et al. (1994) found a positive relationship between the number of a firm’s research alliances and their product development and patenting speed (Deeds et al. 1999: 218). And with regards to network-ties the empirical study of Maurer/Ebers (2006) demonstrates that they are a valuable source of information and knowledge access for firms in the biotech industry, thus increasing their speed of patenting significantly.

In this study we utilize the patent rate because patents are a critical measure of inventive output for firms especially in knowledge intensive industries (Almeida and Kogut, 1999; Ahuja, 2000; Rosenkopf and Nerkar, 2001; Sorensen and Stuart, 2000; DeCarolis and Deeds, 1999). 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 et al., 2000; Hall, 2005). In these industries 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; Powell et al., 1996; Lerner, 1994). 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 research and development process (Kamien and Schwartz, 1982; Dierickx and Cool, 1989; Hagedoorn et al., 2000; Powell et al., 1996).

3. HYPOTHESES

How can external knowledge be accessed in knowledge intensive industries? Within recent research two quite distinct means have been suggested: co-location of firms in knowledge intensive regional clusters, and cooperation of firms in learning alliances and research networks that are not bound to regions (Powell et al. 1996; Christensen, 2003; Shan and Song 1997).

3.1 Regional embeddedness and knowledge access

Our first set of hypotheses is based on a growing body of research pointing to the economic benefits of regional clustering (i.e. Krugman, 1991; Malecki, 1985; Porter, 1998; Pouder and St. John, 1996). Especially for knowledge intensive industries such as biotechnology the importance of local clusters has been emphasized within the literature (i.e. Audretsch and Feldman, 1996; Baptista and Swann, 1998, 1999; DeCarolis and Deeds, 1999; Lynn et al., 1996; McKelvey et al., 2003). The most broadly discussed effect of close proximity is knowledge spillovers. We expect the munificence, the structural diversity and the age of a particular local cluster to have positive effects on the patenting rate of firms in the knowledge intensive biotech industry. We propose the following general hypothesis to guide our subsequent discussion.

Hypothesis 1. The munificence, diversity and age of a biotech firm's regional cluster will have a positive effect on the patent rate.

Our first hypothesis addresses the influence the presence of universities and research institutes in a cluster has on knowledge accessible for biotech firms. These R&D intensive organizations possess regional expertise in certain areas of basic sciences as seen in their inputs (e.g. public and private investments in research) and outputs (e.g. scientific publications, patents and skilled labor). Additionally, they offer valuable research collaborations with firms in the area, supply consulting services and often have expensive instrumentation and facilities small firms may require but can not afford. Furthermore, they are considered key actors in the technology transfer process through out-licensing to firms and fostering firm founding via spin-offs (Cooper, 2000; Gertler, 2005).

The larger the research munificence of the cluster, the greater is the opportunity set presented to firms located in it to access knowledge and therefore innovate through merging their own knowledge with acquired knowledge (Almeida and Phene, 2004; Almeida, Dokko, and Rosenkopf, 2003; Gulati, 1999). There are several mechanisms for accessing the available knowledge. Firms which have spun off from government-funded research institutes or universities typically retain formal appointments in research institutes and universities, and, more importantly, maintain numerous informal networking ties that facilitate flows of knowledge to and from the firm (see Danielle, 2003; Löfsten and Lindelöf, 2002). Additionally, knowledge exchange might be fostered by a local labor pool, pointing to the fact that specialized employees, i.e. scientists, preferably seek jobs within the same geographic area (Angel, 1989; Löfsten and Lindelöf, 2002).

We argue that a biotech firm located in a regional cluster with high research munificence (a high concentration of universities and public or private research institutes) will have access to knowledge flows which are difficult to attain by geographically isolated firms. The higher the research munificence within a cluster is, the greater the opportunities for a biotech firm to access external knowledge (Henderson and Cockburn, 1994; Fleming 2002; Phene et al., 2006). As we have laid out above, this knowledge link will increase the patent rate of biotech firms in several ways: by fostering the development of internal innovative capabilities, by permitting the firm to faster understand and evaluate the importance of external technological advances and by providing valuable feedback to evaluate its own technological position and the potentials of its own innovations. Such feedback will increase the firm´s agility to adjust its research agenda, and speed up the internal research process, resulting in a higher patenting rate. We therefore argue:

Hypothesis 1a. The munificence of a biotech firm's cluster with research institutes will have a positive effect on the patent rate.

Besides these spillover effects from research institutes and universities, there are additional sources of knowledge a cluster offers (Deeds et al., 1999). Alfred Marshall (1890) developed the notion of 'Industrial Districts', incorporating the idea that clusters are comprised of a variety of organizational types and forms, such as suppliers, clients, and service providers. These different organizational types reflect a broad and diverse knowledge base beneficial for a biotech firm's innovativeness in several ways. For example, Gertler and colleagues (Gertler, 2005; Gertler and Quach, 2005) and Salazar and Holbrook (2003; Holbrook and Salazar, 2004) observed in their studies of Canadian biotechnology clusters that the presence of venture capital served as an important pool of valuable and location-specific knowledge. Firm growth benefited from business intelligence in terms of business planning, strategy formulation and coaching. Venture capitalists also facilitated networking for firms by identifying promising licensing opportunities and potential financial partners or by acting as a communication channel for local firms. These networks will provide feedback to biotech firms to evaluate and adjust its research agenda and to optimize its technological development efforts, thus increasing the patenting rate.

Of similar importance was the presence of local specialized service providers, which offered the patenting, accounting, and other consulting expertise many young firms lack in their business development (Gertler and Quach, 2005: 32). In other studies knowledge spillovers did also arise from consulting firms and civic associations such as biotechnology initiatives (Asheim 2002; Prevezer 1998). We therefore expect the density of the cluster regarding supporting organizations to create favorable conditions for a biotech firm's innovative productivity. The accumulated experience and knowledge of these organizations creates a stock of valuable knowledge and arising knowledge spillovers a biotech firm can access (Cooke 2002; Malmberg and Maskell, 1997). This will increase the patent rate of cluster firms as discussed above. We state:

Hypothesis 1b. The density of other organizations in a biotech firm's cluster will have a positive effect on the patent rate.

Refining this hypothesis, we assume that aside from the number of different organizations additional beneficial effects will arise from the diversity of different organizational types within the cluster, and from the cluster age. There are several reasons for the positive effects of knowledge diversity. Firms tend to search for new knowledge in the neighbourhood of their current technological knowledge domain (Nelson and Winter, 1982). However, purely technologically local search restricts the possibilities for innovation through recombination, since it restricts the acquisition of novel and more distant knowledge (Levitt and March 1988; Leonard-Barton 1995). Firms must move beyond technologically local search to compete successfully over time (McGrath, 2001; Rosenkopf and Nerkar 2001). When innovating, the existence of heterogeneous knowledge enriches the possibility of new combinations and thus enhances the likelihood of emergence of novel ideas (Turner and Fauconnier, 1997; Henderson and Cockburn 1996). Hence, it is not just the amount of knowledge that is accessed but the diversity of knowledge available to the firms that will effect the patenting rate by altering the opportunities for new knowledge creation.

The diversity of knowledge will be a function of the organizational variety in the cluster and the age of the cluster. Coevolutionary and mutual reinforcing processes in the founding of core and supporting firms over time shape the structural configuration of the cluster (Mariotti and Piscittello, 2001; Maskell et al., 1998; Shane, 1996; St. John and Pouder, 2003; Stephan, 1996). As a result, the knowledge and capability profile of a cluster elaborates over time with an increasing variety of cluster members (Stephan 1996; Shane 1996). We hypothesize that the diversity of different types of organizations within a cluster will enhance a biotech firm’s patenting rate. This is due to the diversity in knowledge the firm can absorb and exploit, thereby benefiting from knowledge advantages compared to regionally isolated firms.

However, we have to keep in mind that the development of cluster diversity will take time, and that therefore the age of a cluster should be taken into consideration. Within the literature, two lines of argumentation have been suggested. On the one side, increasing cluster age has been attributed to positive effects such as richness and diversity of available knowledge, and increasing efficiency of the supporting infrastructure. On the other side, empirical findings point to negative effects of cluster age, such as overembeddedness, lock-in effects and homogenization of managers perceptions, leading to a decreasing absorption of new ideas and knowledge (Pouder and St. John 1996; Baron, 2004).Given the young history of our empirical setting, we assume that in the German biotech industry positive effects of cluster age prevail, and that increasing age contributes positively to the development of the capability profile described above. This leads us to the following hypotheses:

Hypothesis 1c. The structural diversity of a biotech firm's regional cluster will have a positive effect on the patent rate.

Hypothesis 1d. The increasing age of a biotech firm's regional cluster will have a positive effect on the patent rate.

3.2 Cooperative embeddedness and knowledge access

Our second set of hypotheses draws upon the observation that there might be limitations to the knowledge available within local clusters. Clusters might be incomplete with regard to the various types of supporting organizations, or clusters might be too young to have developed that synergistic "innovation system" profile described above (Wong and He, 2003). This might be especially relevant for our empirical setting, the young German biotech industry. Under these conditions, firms source knowledge internationally (Al-Laham and Amburgey, 2004; Al-Laham and Tsoutaris, 2008; Florida 1997; Serapio and Dalton 1999; Chung and Alcacer, 2002; Cantwell and Janne, 1999). "Internationalization is thus a very important process underpinning these firms' innovative activities and technological dynamism" (Keeble et al., 1998: 333).

Knowledge that is technologically or geographically distant provides the organization with an opportunity to make novel linkages and associations faster (Bloodgood et al. 1996).

We expect the diversity of knowledge in the international context to provide valuable knowledge for innovation. The broader content of knowledge available will provide a more substantiated learning arena for biotech firms (Bathelt et al. 2002), thus increasing their innovation speed significantly. We propose the following general hypothesis which we will refine below.

Hypothesis 2. International alliances of a biotech firm will have a positive effect on the patent rate.

3.2.1 Accessing knowledge through international research alliances

Several scholars have studied the relationship between a firm's research alliances and its innovative performance (Shan et al. 1994; Kotabe and Swan, 1995; Deeds and Hill, 1996; Baum et al. 2000; Lerner et al. 2003). The research has established a link between a firm's research alliances and various indicators of innovative performance, 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). In knowledge intensive industries alliances may lead to the codification of new knowledge through patenting. In the biotechnology industry, for example, collaborations are motivated by a desire to acquire basic knowledge that can be used to create novel molecular entities which are then patented, before they are entered into the development and regulatory process (Rothaermel and Deeds, 2004: 202)

There are several reasons for this influence. Research alliances influence innovation through the creation of trust and reciprocity exchanges (Liebeskind, 1996; Granovetter, 1992) that encourage knowledge sharing and collaboration, the generation of alternative perspectives on research problems and solutions (Powell, Koput and Smith-Doerr, 1996; Dyer and Singh, 1998), and the identification of appropriate referrals to locate new knowledge (Dyer and Noboeka, 2000; Rogers and Larsen, 1984). Research alliances stimulate the development of innovative capabilities and speed up the internal innovation process, thus increasing the rate of patenting (Powell and Brantley, 1992: 371).

In this paper we assume that research alliances with international partners will offer an arena to develop these capabilities faster than alliances with national partners. International research alliances provide a fruitful learning arena due to the greater heterogeneity and diversity of partners' knowledge bases (c.f. Lane and Lubatkin, 1998). Furthermore, operating in multiple national contexts increases the variety of events and ideas to which a firm is exposed, leading to a more extensive knowledge base (Huber, 1991; March, 1991; Barkema and Vermeulen 1998). To sum up, we expect research alliances with international partners to accelerate the development of a biotech firm's innovative capabilities, thereby increasing its rate of patenting. We therefore state:

Hypothesis 2a. The cumulative number of a biotech firm's prior research alliances with international partners will have a positive effect on the patent rate.

3.2.2 Accessing knowledge from network embeddedness

Networks have been analyzed in a variety of ways and through different theoretical lenses in organization studies (for overviews, see Nohria and Eccles, 1992; Oliver and Ebers, 1998). In this paper we state that the examination of a firm's structural network position provides valuable insights into the potential access the firm has to obtain and exchange knowledge, and on the speed in which the firm can transform this knowledge into patentable innovations (Podolny and Stuart, 1995; Rowley and Baum, 2002). There are several reasons for this effect (Shipilov, 2003; Bell, 2005). First, more peripheral firms in the industry are actively seeking involvement with high-status actors. For a lower-status firm, one way of attracting the attention of high-status partners is to offer them access to information or know-how that can be jointly exploited. In this case, high-status firms do not need to conduct time consuming industry-wide searches for novel information, but they can rely upon their partners to bring this information to their attention. Second, high qualified scientists in the industry would rather work for high-status than for the lower-status organizations (Frank, 1985). This human capital brings with it not only its own knowledge, but also the information and capabilities embedded in its own personal networks. Thus, higher status firms are likely to have access to wide and diverse knowledge networks of qualified scientists in their industry, which could be used for conducting industry-wide searches when necessary.

Even more so, central firms have better knowledge of others' innovative efforts (Bell, 2005; Becker, 1970), and have quick access to promising new ventures (Powell et al., 1996) that may generate innovations faster. In addition, central firms may be better positioned to assess the veracity of the information they receive by comparing information across sources (Burt, 1987). Moreover, multiple information sources provide multiple channels to discover new knowledge, and to combine prior and new knowledge in novel ways to generate innovation faster (Van de Ven, 1986).

Although the membership of German biotech firms in the international research network is a quite recent phenomenon, we nevertheless expect beneficial effects from a firm's position within the network on its patenting rate (see Powell et al., 1996, 2005; Hagedoorn and Schakenraad, 2004; Liebeskind et al., 1996). We state that firms who increase their position within the international research network will have faster access to critical knowledge than peripheral firms and should therefore build up their innovative capabilities faster than peripheral competitors. As a consequence, the patenting rate will increase.

Hypothesis 2b. The greater the structural centrality of a biotech firm within the international research network the greater the patent rate.

5. METHODS

5.1 Research setting

Our data setting is the German biotech industry. Hampered by a hostile regulatory environment for genetic research throughout the 1980s and early 1990s, and facing additional institutional constraints, the German biotechnology industry was de facto not existent prior to the mid 1990s (Casper, 2000; Dohse, 2000; Giesecke, 2000; Kaiser and Prange, 2004). However, in the mid 1990s the German government introduced a series of new technology policies designed to orchestrate the development of innovative technologies and small business start-ups (see Dohse, 2000; Ernst & Young, 2003; Giesecke, 2000; Kaiser and Prange, 2004). This and other institutional changes have lead to a dramatic increase in growth rates for German biotech start-ups, and to a pronounced spatial clustering of the industry. Over the last five years, more than 500 new biotechnology start-ups have been founded in Germany, most of them located in clusters around universities and public research institutes (Audretsch and Stephan, 1996; Ernst & Young, 2003). However, most of these bioregio clusters have not been set up from scratch, but have rather been established within an already existing regional infrastructure.

The German biotechnology industry is also an organizational field composed of a wide variety of organizational forms, such as dedicated biotechnology and traditional pharmaceutical companies, and public organizations such as universities and research institutes. The complementary assets held by each type of organization can be consolidated through interorganizational relationships (Gambardella, 1995: 147-148; Mariani, 2004). As a consequence, the biotechnology industry has been identified as the industry with the highest alliance frequency among several industries characterized by high alliance activity (Hagedoorn, 2002). In the German biotech population more than 50% of all research alliances are formed with international partners; moreover organizations from the U.S. comprise the majority of selected partners.

5.2 Data and measures

The data used in the study consists of the complete population of 753 German biotechnology firms in existence in 1995 or founded thereafter. Although the majority of firms were founded after 1995 (roughly 97%), our sample includes firms from the pharmaceutical and chemical industries who have changed their business model and transformed into biotechnology firms. Given that we aim to analyze the entire biotech population we believe that those firms should not be excluded from the analysis. Excluding them would discard valuable information, such as the age of biotech clusters, for example. We used four primary sources to compile the sample. The first were the daily registration and deregistration records of the German Commercial Register ("Bundeszentralregister") in Berlin, the second the "Yearbooks of the German Biotechnology Industry" published yearly by the German company Biocom AG. The addresses from this source were used to identify the geographic location of the firms. The third source were archival data coded from the monthly TRANSCRIPT newsmagazine that reports on the German biotech industry; and from German and European newsmagazines such as FT, FAZ or Handelsblatt. The final sources were the monthly records from the German Patent and Trademark Office in Munich, published by PATOS GmbH as the primary source for the assignment of patents. We purged the consolidated list of companies of all firms which were not German firms, or which were non-independent entities (subsidiaries, divisions and joint ventures) to arrive at 753 companies. These firms were observed from 1995 until the end of 2004.

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. Our variables constructed from the event histories are measured to the day. For example, our dependent variable is accurate to the day of the patent application. Similarly, our alliance variables (international alliances and cluster alliances) are accurate to the day that the agreement is signed. 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 began 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. In those cases where only the month and year of an event could be determined, the day was set at the midpoint of the month to minimize errors in timing. Given this structure our data consists of 5154 observations (monthly spells) of 753 firms.

5.2.1 Dependent variable

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

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

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. For the period under observation (1995-2004) 1011 patents have been filed. The patent applications are accurate to the day, e.g. a patent may be applied for on June 15th 1999 and the event is coded as occurring on that specific day. Following prior research, we assign a patent to a biotech firm at the date of application rather than the date of granting. There may sometimes be a lag between the file date and the granted date. The file date is a more accurate representation of the date of invention.

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 (Dutta and Weiss, 1997; Henderson and Cockburn, 1994; Jaffe, Trajtenberg, and Henderson, 1993; Engelsman and van Raan, 1994; Albert et al., 1991; Narin, Noma, and Perry, 1987, Rosenkopf and Nerkar 2001). We have to acknowledge that there are a number of potential limitations to using patent data to study innovation. 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 (Ernst & Young, 2003; 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.

5.2.2 Independent variables

Our primary independent variables are research munificence of local clusters, density of local supporting cluster (four variables), cluster diversity (Herfindahl), cluster age, prior research alliances of the firm with foreign partners and research network centrality of the firm. To measure the research munificence of the local clusters (RES_Perc) we coded for the number of universities and private or public research institutes located in the same 2-digit postal code area as the firm. We then divided the count of research institutes within the cluster by the total number of organizations in the cluster. Thus, with the same number of research institutes in two clusters, the one with a smaller number of organizations has a higher research munificence than the one with a larger number of organizations. The location information to construct the clusters was taken from the postal addresses published yearly in the Biocom AG Yearbooks. The German postal system uses a 5 digit system, whereas the first digit reflects the city, the second digit the suburbs within the city, and the last 3 digits the street level. Clustering at the 2-digit level represented a compromise between a smaller geographic region such as the street level, and a larger regions such as the city district or the state ("Bundesland"). Our measure therefore reflects a significant smaller area then the Metropolitan Statistical Area (MSA), that is commonly used in U.S. based cluster studies (c.f. Audretsch and Stephan, 1996; DeCarolis and Deeds, 1999; Krugman, 1991; Shaver and Flyer, 2000; Zucker et al., 1998).

To measure the density of the local supporting cluster we constructed four variables (ORGTYPE I-IV). We coded for the number of core-biotechnology firms (ORGTYPE I), laboratory equipment and material suppliers (ORGTYPE II), consulting firms such as IT-Services or management consultants (ORGTYPE III) and pharmaceutical and biochemical firms (ORGTYPE IV) located in the same 2-digit postal code area as the firm. Information on all of these organizations was taken from the annual yearbook published by Biocom AG. Our cluster variables are thus updated annually.

To measure the diversity of the local cluster we constructed the Herfindahl index according to the formula:

$$H = \sum_{i=1}^{n} (s_i^2)$$

where s_i is the density of organization i in the cluster, and n is the number of different organizations. The density s_i was calculated as the number of each organizational type (I-IV) in the cluster divided by the total number of organizations in the cluster. The density measures were then squared and summed to calculate our diversity measure. Thus the index describes the entropy of organizational types in the cluster, considering cluster size.

To measure cluster age we had to define a starting time for the existence of the biotech cluster. The founding of a biotech cluster was defined to correspond with the time of the first founding of a biotech firm in the cluster, e.g. the local 2 digit postal region. This allowed us to calculate cluster age for any event for each organization in the cluster by subtracting the starting time of the cluster from the time of the event (in days). We therefore measure how old the cluster is whenever an event under observation occurs.

Our next primary variable, international research alliances, was a cumulative count of the strategic research alliances a firm has established with foreign partners, e.g. all non-German partners. The international alliances are thus R&D agreements between a German biotechnology firm and a partner based in another country. This variable (as well as the local alliance variable) was updated on the day that an alliance was formed. Finally, due to the structure of our data we were able to use the information on all national and international R&D alliances of a firm to construct a series of quarterly networks. Bonacich's (1987) eigenvector centrality was used to measure the status of a German firm in the biotech industries international research network for each quarter of a given year. All national and international research and development alliances of German firms in effect during a quarter were used to construct the research network for that quarter. The UCINET program was used to construct the quarterly Bonacich (eigenvector) centrality score for each organization in the network. This indicator can formally be defined as:

$$s_t(a,B) = \sum_{\kappa=0}^{\infty} aB^{\kappa}R_t^{\kappa+1}\mathbf{1}.$$

In this expression, a is a scaling coefficient, B is a weighting parameter that can range between zero and the absolute value of the inverse of the value of the maximum eigenvalue of the sociomatrix R_t, 1 is a column vector where each element has the value "1," and s_t is also a column vector where element $S_{i,t}$ denotes the status of biotech firm i. Given this specification, a biotech firm's status is a function of the number and the status of the firms with which it forms cooperative research agreements. In turn, the status of these partners is the function of the number and the status of their partners, and so on. The B parameter is set equal to the reciprocal of the maximum eigenvalue. We used the Bonacich (eigenvector) measure of centrality because we believe it to be the preferred measure of status or prestige (rather than information flow or brokerage) since it takes into account not only the number of ties but the centrality of the partners.

5.2.3 Control variables

We included as controls a number of variables at the firm level known or expected to affect the likelihood of patenting but not included in our hypotheses. One firm-level control was age, measured as the number of days since the founding or qualification of the firm. The second control variable was size, measured by the number of employees the firm reported employing. Third, we controlled for the number of local alliances the firm is involved in, that is the number of research alliances a biotech firm has established with a partner located within it´s 2 digit postal code. In addition, we used two variables to measure the absorptive capacity of a firm to control for her ability to recognize the value of new, external knowledge, assimilate it, and apply it to commercial innovations (Cohen and Levinthal, 1990).

The first control for absorptive capacity was technological sophistication of the firm as an indicator of the complexity of her technological knowledge base. To measure the sophistication of technological capabilities we coded the laboratory types firms reported to utilize (Casper 2000). A total of 8 laboratory types were used to classify each firm: chemical lab, chemical-biological lab, L1, L2 and L3-Lab, S1, S2 and S3-Lab. These lab-types are classified according to the requirements of the German Ministry for Education and Research. Among these classifications, L3 and S3 laboratories reflect the highest technological complexity and security standards. We therefore constructed a dummy indicating whether the firm was utilizing a L3 or S3 laboratory.

The second control for absorptive capacity was the number of research domains of the firm as an indicator of the breadth of the knowledge base of the firm. We used the self-reports of firms compiled in the Yearbook records to classify each firm, e.g. gendiagnostics, polymer protein coating, tissue engineering, among others. A maximum of 13 research domains were reported by the firms. The number of research domains in which firms were active was a simple count. Although the number of research domains is relatively stable there are fluctuations over time. We included an interaction term (ACINT) to control for moderating effects of absorptive capacity. This interaction term is the product of the number of research domains and the cumulative number of prior international alliances, reflecting a firm's ability to transfer, assimilate and apply the knowledge from foreign partners into innovative outcomes (patents). The final control variable was prior patents of the firm. The annual number of corporate patents granted in genetic engineering was used to measure cumulative patent activity. The German Patent and Trademark Office in Munich publishes information on the date of every patent issued, and this source was used to construct the number of patents granted to biotech firms each year.

5.3 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 modeled as a stochastic point process (Amburgey, 1986). The alliance 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 that:

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

The use of an exponential baseline model such as the one above is common in event history analyses. Since we include two different functions of time (age of the firm and age of the cluster) as explicitly measured covariates we did not use a Weibull specification to add a second model parameter for monotonic time dependence. To test for model sensitivity we ran the analyses using a different distributions, a weibull model and a model based on a partial likelihood, a Cox regression. We have also tried a frailty model with an exponential baseline distribution and a gamma distributed frailty term. The results show that our original model specification has the highest fit with the data, and leads to very robust findings.

Parameters were estimated using maximum likelihood with the STATA program. The estimation procedure clustered observations by firm 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 describes the improvement in fit between hierarchically nested models and follows 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 nine primary variables. This model was used to evaluate the hypotheses. In comparing the full model to the control variables only model 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 2 nested models.

6. RESULTS

Table 1 provides means and standard deviations for the variables in our models as well as a correlation matrix. Table 1 indicates relatively moderate intercorrelations among the independent variables. Given the large number of observations in the data multi-collinearity is not likely to be a problem.

-Table 1 About Here-

Table 2 provides the results of our event history analysis. Model 1 provides parameter estimates for only the control variables. Model 2 adds parameter estimates for the nine primary variables. Model 2 is not only a significant improvement over a constant rate model, a likelihood ratio test comparing model 2 with model 1 indicates that it provides a significantly better fit with the data. The parameter estimates in model 1 indicate that five of the control variables have a significant impact on the rate at which firms patent: age, size, research breadth, number of prior patents, and local alliances. The parameter estimates in model 2 provide support for two of our hypotheses: foreign linkages and network centrality increase the patenting rate of German biotechnology firms. However, we do not find significant cluster effects, nor any effects for alliances within the cluster, which we included as a control in the model. We therefore reject our general hypothesis 1, as differentiated in hypotheses 1a, 1b, 1c and 1d.

Our measure for prior international research alliances is significant and positive, providing support for hypotheses H2a. The same effect occurs for structural position in the research network. Our measure for positional embeddedness within the German research network, the eigenvector centrality, is significant and positive, confirming hypothesis H2b.

-Table 2 About Here-

7. DISCUSSION AND CONCLUSION

Despite a broad stream of literature pointing to benefits of local knowledge access, our data do not support our first set of hypotheses: the parameter estimates for our local cluster measures are not significant. In explaining this interesting finding we invoke several possible reasons. First, it might be that the only benefits firms can gain from being located within a dense cluster - compared to firms outside the cluster - are cost advantages (Bania et al., 1992; Maarten de Vet and Scott, 1992; Malecki, 1985; Saxenian, 1990). Although these factors might be important for a firm's initial founding decision and for its operational costs of doing business within a region, they might not speed up innovations success in the form of patenting speed.

Second, the life cycle of the cluster might be a factor of consideration. Findings by Pouder and St. John (1996) suggest that the same forces promoting firm growth and expansion in an initial stage can offset clusters' positive impact in a later stage, when the density of ties has increased significantly (see also Baron, 2004). The underlying reasons might be similar to the effects that have been observed in dense networks, network rigidity and network homogeneity (see Uzzi, 1997). Network rigidity may be exacerbated by proximity - a strongly shared cognitive frame in a local network may make local firms insensitive to contradictory information and new perspectives, which seem crucial for innovation (Grabher, 1993; Kogut et al., 1993; Pouder and St. John 1996; Grabher 1993). A related explanation would be that young clusters – such as in the population under observation – have not had sufficient time to develop a critical mass of "regional competence" (Dohse, 2000: 1127), reflected in technological know-how of start-ups and entrepreneurial experience of local venture capitalists, consultants, and other service providers that has shown to be beneficial in more mature innovation clusters (Cooper, 2000).

Third, we see structural reasons in the institutional setup of the German innovation system. In that vein, specifics in the public-sector status of universities and research institutes in Germany might explain the lack of knowledge spillovers from universities to biotech firms within the clusters (see Giesecke, 2000; Lehrer and Asakawa, 2004). The institutional design of the public sector in Germany historically aimed at securing the independence from private interests, leading to substantial autonomy as well as restrictions for civil servants, i.e. making dual public-private appointments difficult. Therefore, knowledge spillovers might be restricted by the institutional specifics of the German system described above.

The lack of knowledge within local clusters as well as the structural impediments to knowledge spillovers might be the main reason why firms turn outside their local clusters to source knowledge on an international level. The findings of our analysis support our hypothesis in showing that the number of prior international research alliances the firm is involved in significantly increases her patent rate. Partnering thus helps firms to build up their own innovation capabilities and increase their innovation effectiveness, as reflected in the patent rate (Henderson, 1996; Kogut and Zander, 1996; Rothaermel and Deeds, 2004). Interestingly, comparing the magnitude of the coefficients influence in table 2, international research alliances show by far the highest influence on the innovation speed of German biotech firms. There is even a higher influence from the embeddedness in international alliances than from a broad internal research base of the firm. We explain this finding in several ways. First, international alliances do not only provide firms with missing capabilities and technologies, but in addition provide a fruitful arena to develop innovation related capabilities due to the greater heterogeneity and diversity of their partner's knowledge bases. The latter has been discussed as being a prerequisite for a high degree of relative absorptive capacity of partners (c.f. Lane and Lubatkin, 1998; Rothaermel and Deeds, 2004), increasing learning effectiveness especially in an international context (Barkema and Vermeulen, 1997; Salk et al., 2001). Even more so, research in international management has shown that firms who operate in international markets develop a richer knowledge structure and stronger learning skills due to the diversity of stimuli from their environment (Barkema and Vermeulen, 1997, 1998). According to our findings the same effect holds for network ties.

To sum up, in this paper we developed several hypotheses linking a firm's access to external knowledge sources to its innovative success. While prior research has separated the effect of co-location versus cooperation on innovative success, we combine both streams of research, thereby developing a more refined picture of firms' knowledge sourcing options. Our findings contribute to a more recent stream of research indicating that cluster membership is not a sufficient precondition for innovative success (Brown and Hendry, 2006a and b; Mangematin et al., 2003; Mariani, 2004). The maturity and stage of the development of a cluster might be an important contingency to consider. Given our findings, younger clusters seem to lack the knowledge and skills that firms in high technology industries require for innovation. That knowledge seems to be less likely available locally, but more available within the cross-sectoral network of research ties. Being embedded in that network, and even more so being central in the network seems to matter most. Second, connecting to the international arena helps to overcome firms the limits of their regional niche with regards to knowledge, technologies, or the experience in developing innovations. Our work therefore points to the benefits of the early stage internationalization of technology-intensive firms. By empirically confirming the importance of international linkages for start-ups we contribute to the field of international entrepreneurship and to the emerging network based view in international management (Dunning, 1998; Jones and Coviello, 2005; Keeble et al., 1998). An interesting extension of our research might address the question whether the increased patent rate due to international linkages acts as a facilitator for future internationalization efforts, for example by signaling a firms attractiveness as an international alliance partner.

Third, our findings point to the importance of alliances as a vehicle or means of internationalization that helps firms to overcome the hazards of the “liability of foreignness”, that have been well documented elsewhere (Mezias, 2002; Zaheer, 1995). The management of these alliances and the development of “alliance capabilities” therefore becomes crucial (Hoang and Rothaermel, 2005). Firms in knowledge intensive industries have to develop research linkages on a dyadic or network level early on. Firms should also try to take a central role in the network early on, for instance by connecting to high status firms such as biochemical or pharmaceutical firms in the form of research projects or joint development projects.

10. REFERENCES

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TABLE 1: Descriptive Statistics

Variables	Mean	S.D.	1.	2.	3.	4.	5.	6.	7.	8	9	10.	11.	12.	13.	14.	15.	16.
1. Age (Days)	1278	1347	1.00															
2. # of Employees	36.64	84.00	.257*	1.00														
3. Techn. Sophistication	.026	.160	.0034	-.032	1.00													
4. Research Breadth	1.63	2.96	.151*	.088*	.015	1.00												
5. AC_INT	.90	5.62	.119*	.162*	-.010	.445*	1.00											
6. Prior Patents	3.34	13.58	-144*	-.020	.602*	-.013	.002	1.00										
7. Research Munificence	.30	1.64	-.132*	-.131*	.118*	.058*	-.019	-.024*	1.00									
8. Competitor Density	14.92	12.25	.046*	.094*	-.121*	.052*	.150*	-.136*	.279*	1.00								
9. Supplier Density	12.62	7.09	.081*	.160	-.175*	.002	.050*	-.213*	.217*	.693*	1.00							
10. Consultants Density	3.82	3.41	.058*	.097*	-.046*	.009	.052*	-.126*	.461*	.358*	.390*	1.00						
11. Pharma Density	1.17	1.37	.108*	.164	-.089*	.044	.098*	-.098*	.022	.287*	.416*	.214*	1.00					
12. Cluster Diversity (Herfindahl)	.327	.079	-.055*	-.094*	.397*	-.001	-.011	.639*	-.163*	.-.181*	-.305*	-.484*	-.275*	1.00				
13. Cluster Age (Days)	3690	2397	.259*	.211*	-.075*	.041	.065*	-.111*	.382*	.225*	.192*	.401*	.091*	.220*	1.00			
14. # Prior Cluster Alliances	.201	.857	.069*	.247*	-.045*	.016	.222*	-.021	-.044*	.265*	.181*	.228*	.043*	-.064	.136*	1.00		
15. Prior International Alliances	.447	1.77	.222*	.638*	-.032	.035	.327*	-.004	-.065*	.213*	.173*	.065*	.172*	.092*	.166*	.507*	1.00	
16. Int. Network Centrality	1.598	10.732	-.009	.147*	-.030	-.044	.021	-.029	.141	.043*	.043*	.191*	-.084*	-.068*	.115*	.487*	.141*	1.00

* correlations significant at p<.05 based on 5154 observations

TABLE 2: Hazard Rate Model of the Patent Rate

Variables	Model 1	Model 2
Age	.000307●	.0002848●
	(.00004)	(.00004)
Size (No. of Employees)	.00250●	.0019312 ●
	(.00067)	(.00072)
Technological Sophistication	-1.9411	-1.59132
	(2.2918)	(1.560806)
Research Breadth	.09244●	.1067537●
	(.02490)	(.023496)
AC_INT (RB * IntAll)	-.003207	-.0082951
	(.010138)	(.01080)
Number of Prior Patents	.020603●	.02404●
	(.00629)	(.0048872)
Number of Prior Local R&D Alliances	.425356●	-.3234119
	(.09544)	(.1698787)
Cluster Research Munificence (RES_Perc)		-.3570537
		(.6291001)
Cluster Competitor Density (ORGTYPE I)		.0219632●
		(.0106819)
Cluster Supplier Density (ORGTYPE II)		-.0007457
		(.0179364)
Cluster Consultant Density (ORGTYPE III)		-.0029409
		(.0348146)
Cluster Pharma Density (ORGTYPE IV)		-.0308643
		(.0942299)
Cluster Diversity (Herfindahl)		-2.977548
		(1.176005)
Cluster Age		-.000001
		(.00004)
Number of Prior International R&D Alliances		.1667691●
		(.0333759)
Centrality in the International R&D Network		.053677●
		(.0083472)
Number of Observations	5154	5154
Number of Patents	1011	1011
Chi-squared	260.46	1218.99
Degrees of Freedom	6	16
P Value	p<.001	p<.001

● Significant at p<0.05