

# **Do Firms benefit from being present in Technology Clusters?**

## **Evidence from Firms active in the Field of Biotechnology**

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### ***Abstract***

This paper investigates whether firms active in biotechnology can improve their technological performance by being present in regions that host a concentration of similar technological activity. Biotechnology clusters are identified at the level of US states, Japanese prefectures and European NUTS2 regions. Based on a panel data set of 59 consolidated biopharmaceutical firms (period 1995-2002), we find empirical evidence for a positive albeit diminishing relationship (inverted U shape) between the number of technology clusters in which a firm is present and its subsequent overall technological performance. Presence in other (non-cluster) regions on the contrary, has no significant impact on the firm's technological performance.

**Keywords:** Technology Clusters; Knowledge Spillovers; Biotechnology

## ***Introduction***

Firms need to innovate in order to sustain and extend their competitive advantage. At the same time, it has been observed that innovative activities of firms display a great tendency to cluster, especially in knowledge-intensive industries (AUDRETSCH and FELDMAN, 1996) where the generation and application of new knowledge is crucial. Agglomeration externalities such as the access to a highly-skilled pool of labor and specialized suppliers, and the occurrence of localized knowledge spillovers are expected to yield benefits for firms located in clusters (MARSHALL, 1920; PORTER 1990; 1998). Surprisingly little empirical work has examined whether firms can actually enhance their overall innovative performance by developing R&D activities in technology clusters worldwide. Studies in economic geography, using single plant data (mostly the firm's headquarter), found evidence that firms in clusters are more innovative than firms located outside clusters (ex. BAPTISTA and SWANN, 1998; DEEDS, DECAROLIS and COOMBS; 1999; BEAUDRY and BRESCHI, 2003; BATEN et al., 2007; VAN GEENHUIZEN and REYER-GONZALES, 2007). In addition, they found that positive performance effects from being located in a cluster are conditional on certain cluster characteristics such as the amount of accumulated knowledge in the cluster (BEAUDRY and BRESCHI, 2003). However, as cross-sectional data is used in these studies and the heterogeneity of firms in terms of innovative capabilities and efforts is only taken to a limited extent into account, these studies do not reveal whether firms really improve their innovative performance by locating in a cluster. Yet, the R&D internationalization literature provides evidence that firms are increasingly setting up R&D activities in different regions in order to benefit from agglomeration externalities (GASSMAN AND VON ZEDTWITZ, 1999). Those multi-location firms with a network of geographically dispersed R&D units seem to be very suitable vehicles to tap into local pockets of excellence and thereby benefitting from the productivity and innovation advantages of clusters. However, so far, empirical evidence remains inconclusive in terms of the overall performance effect of presence in multiple regions and clusters (PENNER-HAHN and SHAVER, 2005; SINGH, 2008). In addition, studies of R&D internationalisation usually do not consider the technological strengths of the regions in which R&D activities are being deployed.

In this paper, we analyze the relationship between the geographical dispersion of the firm's technological activities - including the presence in technology clusters -

and its overall technological performance, using a panel of 59 biopharmaceutical firms (period 1995-2002). This article complements and extends these studies in three important ways. First, the identification of *technology clusters* has been undertaken on a *global scale*. Second, whereas previous studies used single plant data, we perform analyses at the level of the *consolidated firm*, i.e. taking into account the technological activities undertaken by all the subsidiaries of a firm. Third, we use *panel data* instead of cross-sectional data, which enables us to control for the heterogeneity of firms. Our results provides evidence for an inverted U-relationship between the number of R&D clusters in which a firm is present and its subsequent overall technological performance, while no significant performance effect can be observed from being located in other (non-cluster) regions.

The remainder of the paper is organized as follows. First, we provide an overview of prior research on clusters and firm performance. Next, the data sources and variables used in this study are presented, followed by the empirical results. Conclusions, limitations and directions for further research are discussed in the final section.

### ***Clusters and Firm Performance***

The clustering of industrial activity in well-defined and relatively small geographic areas has been observed for long time by economic geographers and regional scientists (MARSHALL 1920; KRUGMAN 1991; PORTER 1990). Famous examples of *industrial* clusters include Detroit's car industry, the entertainment industry of Hollywood and the fashion shoe companies in northern Italy. In his theoretical work on "industrial districts", MARSHALL (1920) highlighted three incentives for firms to cluster geographically: (i) broader access to specialized, highly-skilled labor force; (ii) access to specialized suppliers; and (iii) the presence of inter-organizational knowledge spillovers<sup>1</sup>. Presence in technology clusters is expected to enhance the innovative capacity of cluster participants in two important ways. First, local agglomeration of specialized resources and the presence of knowledge spillovers allow firms to operate more productively (MARSHALL, 1920). Next, opportunities for innovation (both new buyer needs as new technological possibilities) are more visible in a cluster and competitive and / or peer pressure among firms is higher (PORTER, 1990; 1998), thereby stimulating firms to be more innovative.

Also today, the clustering of firms in particular fields remains a striking feature of national and regional economies despite more widely available and faster transportation and communication infrastructure, and the presence of global markets from which resources, capital, technology and other inputs can be more efficiently sourced (PORTER, 1998; 2000). Following the success of Silicon Valley in California and Route 128 in Boston, recent years have witnessed a renewed interest in the innovative and economic potential of so-called *technology* clusters that built on the local presence of unique technology resources and entrepreneurial dynamics (SAXENIAN, 1994; ST. JOHN and POUDEUR, 2006). Broader than traditional industry categorization, technology clusters capture important linkages, complementarities, and spillovers from technology, skills, information, marketing and customer needs that cut across firm and industry boundaries (PORTER, 2000; ST. JOHN and POUDEUR, 2006). The dynamism in “technology districts” is founded on production-based technological learning among firms (STORPER, 1992). Given the observation that part of the technological knowledge created in clusters is new, complex and of a more tacit nature (POLANYI, 1966; NONAKA, 1994; VON HIPPEL, 1994), knowledge exchange and interactive learning which are essential in the innovation process (LUNDVALL, 1992) are facilitated by spatial proximity and tend to be less tradable or available from elsewhere. The innovation dynamics in clusters are further reinforced by vigorous local competition between interconnected firms (PORTER, 1998) and the presence of entrepreneurial universities and supporting local institutions and government.

However, as clusters grow diseconomies of agglomeration such as congestion effects, increasing real estate prices and rising salaries, may arise eroding the initial agglomeration and cost advantages of firms within the cluster (POUDEUR and ST. JOHN, 2006). In addition, when industries or technologies reach the maturity stage, innovations may become more incremental, new job and new firm creation will decrease and clusters may lose their initial competitive edge. Eventually firms within a cluster may become more vulnerable to the emergence of completely new, disruptive technologies. However, as long as the level of internal rivalry within the cluster is sufficiently high and firms remain outward-looking and innovation-seeking, firms can partially compensate for some decline in the cluster’s competitiveness (PORTER, 1998).

Cluster theory suggests that the capacity of firms to innovate extends beyond the organizational boundaries of the firm and increasingly depends on the assembled resources - essential in the innovation process - that agglomerate in specific places (FELDMAN and FLORIDA, 1994). Studies in the economic geography literature have investigated whether firms located in industrial or technology clusters are more innovative<sup>2</sup> than firms outside clusters. These economic geography studies use cross-sectional data, at the level of *single plants* (mostly the firm's headquarter), and provide some interesting insights on cluster characteristics.

A first set of relevant studies in this line of research have investigated whether manufacturing firms from a diversity of sectors, benefit from being located in a region with a high *concentration of industrial activity* in the same industry. For the United Kingdom, BAPTISTA and SWANN (1998) found a positive effect from own sector employment on the likelihood of firms to innovate (measured by innovation counts). In contrast, regional employment in other sectors had no effect on the innovative performance of firms. Using data of manufacturing firms in the United Kingdom and Italy, BEAUDRY and BRESCHI (2003) found evidence that clustering alone is not leading to better innovative performance of firms (measured by patent counts). Only the concentration of other *innovative* firms in the same industry (measured by employment) is contributing to a higher innovative performance of firms, a finding which has been confirmed by the study of BATEN et al. (2007) for firms trading in the state of Baden (Germany) around 1900. In addition, BEAUDRY and BRESCHI (2003) also observed that the *accumulated knowledge stock* in a cluster – both in the firm's own industry as in other industries – has a significant positive effect on the innovative performance of firms. This suggests that for the firm's innovative performance, the actual size of the knowledge creation activities within a particular region is more important than the overall industrial activity per se.

A second set of studies in the economic geography literature differentiate regions into *clusters and non-cluster regions* based on the amount of technological activity in developed into a region, and then examines whether firms located in those technology clusters are more innovative than firms located outside clusters. VAN GEENHUIZEN and REYER-GONZALES (2007) define clusters as regions with at least one knowledge institute and 10 young entrepreneurial biotechnology firms<sup>3</sup>. They distinguish between clustered and non clustered companies in the Netherlands and

found no significant effect from location in a cluster on the innovativeness of biotechnology firms (approximated by the number of R&D employees). However, when only the largest and oldest biotechnology cluster in the Netherland – the Leiden region- is considered as a clustered location, a significant effect from cluster presence is found. These results seem to suggest that *critical mass* is needed before agglomeration effects take place. DEEDS, DECAROLIS AND COOMBS (1999) take into account the variance in concentration of biotechnology activity in the eight clusters identified as biotechnology clusters in the United States (at the MSA level). The share of the nation's total biotechnology firms located in that region is used as concentration measure. The study shows a significant impact of cluster presence on the firm's innovative performance. In addition, firms located in a cluster with a higher concentration of biotechnology firms develop significantly more new products than firms located in regions with lower concentrations of those firms. The study also provide support – although from a weak nature ( $p < 0.10$ ) - of an inverted U relationship between the concentration of biotechnology firms in a firm's geographic region and the number of new products developed by the firm. These results suggests that as clusters grow, negative agglomeration effects due to congestion and increased competition may start to erode some of the positive agglomeration externalities.

While the economic geography literature has studied the impact of location at the level of single plant firms, the R&D internationalization literature provides evidence that firms are increasingly deploying R&D activities in *multiple regions* hosting similar industrial and technological activity (HEAD et al, 1995; SHAVER and FLYER, 2000; CHUNG and ALCACER, 2002; ALCACER and CHUNG, 2007, CANTWELL and PISCITELLO, 2005). R&D surveys further reveal that firms' (re)location choices are driven by technology factors such as the presence of high-quality scientists and engineers, the proximity to universities, and the access to information on local science and technology (FLORIDA, 1997; KUEMMERLE, 1999). A few studies have investigated the impact of location choices on the *overall innovative performance of firms*. IWASA and ODAGIRI (2004) found evidence for a significant positive effect of the local technological strengths of regions (US states) in which the R&D subsidiaries are located on the overall innovative performance of the parent firm in Japan. Their results suggest that sourcing is done within own technological fields, with possibly also spillovers effects from technologically related fields. FURMAN et al. (2006)

analyzed the overall innovative performance of nine large multinational firms in the pharmaceutical industry at the level of 13 therapeutic classes. In their study, clusters are identified as regions that generate the greatest number of life sciences publications on a worldwide scale<sup>4</sup>. They found that at the level of therapeutic classes, the overall research productivity (measured by the number of patents grants) of firms is positively promoted by the presence of local knowledge. However, this result is primarily driven by the positive impact of publicly generated knowledge, while privately generated knowledge is found to be negatively correlated with the firm's research productivity. The latter finding suggests that firms may experience negative productivity effects from competing too closely with rivals.

These studies in economic geography at the single plant level and some additional studies at the aggregated firm level use *cross-sectional data*<sup>5</sup> to investigate whether firms benefit from being present in clusters. The use of cross-sectional type of data, however, raises concern that unobserved firm heterogeneity may affect the results (see also SINGH, 2008). Investigating whether firms can really enhance their overall innovative performance by developing geographically dispersed R&D activities in multiple clusters requires time series on firm's overall technological performance and the location of its R&D subsidiaries. Studies in the R&D internationalisation literature typically use *panel data* to study the link between geographical dispersion of R&D and the firm's overall performance. However, empirical work on this topic is still quite recent and the results remain largely inconclusive. PENNER-HAHN and SHAVER (2005) observed that Japanese ethical pharmaceutical firms (period 1980-1991) that engaged in international R&D activities (measured by a dummy variable) benefitted in terms of technological performance (number of patent grants). In line with this research, CRISCUOLO (2008) found a positive relationship between the *market value* of multinational firms in the pharmaceutical and chemical sector (period 1990-2005) and the geographic dispersion (measured by Herfindahl index and network spread index) of their research activities (publications) over different countries. In contrast, SINGH (2008) provide evidence for a negative effect from R&D distribution (measured by a R&D geographic spread and a R&D dispersion index) over multiple countries and US regions (MSA level), using a panel of 1127 consolidated manufacturing firms over the period 1986-1995. FURMAN et al. (2006) also found evidence that presence in multiple life science clusters has a

negative impact on the innovative performance - at therapeutic class level - of pharmaceutical firms (period 1981-1990). The results of this study however, have been obtained without controlling for firm fixed effect<sup>6</sup>. R&D internationalisation studies further indicate that – beside the geographic configuration of R&D - other organisational factors such as the extent of the local subsidiary's embeddedness in the host country's productive and innovative networks (CRISCUOLO and AUTIO, 2008) as well as the knowledge integration mechanisms employed by the multi-location firms (SINGH, 2008) may have important performance implications for the assimilation, cross-fertilisation and recombination of geographically dispersed knowledge. Unlike the economic geography literature, impact studies in the R&D internationalisation literature have mainly investigated firm's location choices at the country level, while the cluster literature suggests that many of the location advantages reside in the subnational, i.e. the regional level. In addition, this stream of literature does not take into account the characteristics of regions in which R&D activities are being deployed.

In this paper, we examine whether firms active in a complex, knowledge-intensive industry, namely biotechnology, where the generation and application of new knowledge is crucial for the production of innovations, benefit from being present in technology clusters. Our study complements and extends previous performance studies in three important ways. First, the identification of biotechnology R&D clusters is not restricted to one particular country but is done on a more global scale, at the level of US states (n=50), Japanese prefectures (n=47), and European NUTS2 regions (n=220 for EU-15 and Switzerland). In line with the observations made by BEAUDRY and BRESCHI (2003), we focus explicitly on the role of a cluster's pool of technological knowledge in relation to firm's innovative performance. Therefore, we first define all regions that account for at least 1.5% of the worldwide number of EPO patent applications (1990-1999) in the field of biotechnology, as biotechnology clusters (n=20). Note that these patent applications originate from firms as well as universities, research organizations, hospitals and individuals. Second, as R&D intensive firms often organize their R&D activities within different units - located in different regions - analyzing the production of knowledge in these firms can not be confined to a single location. So, whereas previous studies in the economic geography literature analyzed presence within a cluster from the

perspective of a single plant (e.g. by considering only the firm's headquarters), we opt for using consolidated firm data, taking into account the location of headquarter facilities and all other subsidiaries. Third, we use panel data instead of cross-sectional data, which allows us to analyze the relationship between the number of technology clusters in which a firm is present and the subsequent impact on the overall technological performance of the firm, while controlling for the heterogeneity across firms. We expect a positive effect on a firm's overall technological performance from being present in multiple regions, as this coincides with an increased access to state-of-the-art knowledge available within each of these regions. At the same time, the more one is already involved in different regions, the smaller the additional effects in terms of access to new, relevant knowledge might become. In addition, presence in multiple regions may result in decreasing innovative performance due to increasing costs of coordinating multiple R&D units and difficulty from leveraging knowledge from multiple locations (SINGH, 2008). Building on the aforementioned research, we hypothesize that location benefits principally stems from presence in technology clusters. Given the presence of critical mass and the agglomeration of relevant knowledge in technology clusters, we expect that the relationship between the extent of cluster membership and overall technological performance should be distinctive from a mere multiple location effect.

### ***Empirical Model and Variables***

To investigate whether firms experience a technological premium by locating in technology clusters, European patent application data have been used to 1) create indicators of firms' technological activities in the field of biotechnology, 2) to identify on a global scale biotechnology clusters and finally, 3) to assess the presence of firms in biotechnology clusters and other regions.

The use of patent data has several advantages. They are easy to access, cover long time series, and contain detailed information on the technological content, owners and inventors of patented inventions. This allows to mark out biotechnology patents and to construct indicators of the technological performance at the level of firms and regions. At the same time, it could be noticed that patent indicators also have some deficits. Patent propensities vary across industries and firms, patented inventions vary in quality, and not all inventions are patented (Basberg, 1987;

GRILICHES, 1990). Given the specific industry under study – biotech industry – patent indicators do qualify as relevant approximations of innovative activities undertaken by firms, as this industry displays a high propensity to patent (ARUNDEL and KABLA, 1988). Moreover, studies comparing patents with other indicators of technological knowledge, such as product announcements in trade and technical journals or expert opinions, have reported strong correlations between different indicators of R&D activity, both on the level of the firm (HAGEDOORN and CLOODT, 2003; NARIN and NOMA, 1987) and on the regional level (ACS et al, 2002) – thus establishing patents as a good indicator of novel technical activity.

In this study, patent indicators are based on European patent application data. Due to the extensive time periods observed between application and granting decisions<sup>7</sup>, we opted for patent applications as the more correct indicator of ongoing technological activity, rather than for patent grants. Since patent applications from European Patent Office (EPO) are published 18 months after filing date, while - until recently (March 2001) – patents from the United States Patent and Trademark Office (USPTO) were only published if, and when, granted, we decided to work with EPO patent data rather than the more commonly used USPTO patent data. As EPO patents are considered to be, on average, of a higher quality than USPTO patents due to the higher cost of patenting (VAN POTTELSBERGHE DE LA POTTERIE and FRANÇOIS, 2006) and the lower patenting rate at the EPO office compared to the USPTO office (QUILLEN and WEBSTER, 2001), we assume that the choice for EPO patent data<sup>8</sup> will have no impact on the results. In addition, our choice for EPO patents rather than USPTO patents has also been motivated by the incompleteness of the assignee and inventor address information on numerous USPTO patents, due to which these patents can not easily be assigned to US states, European regions or Japanese prefectures.

### **Sample of Biopharmaceutical Firms**

For the selection of our sample of biopharmaceutical firms, we started from a dataset with all EPO patent applications in the field of biotechnology. This dataset is the result of previous research efforts by GLÄNZEL et al. (2004) to delineate technological activity in the field of biotechnology<sup>9</sup>. Based on a list of all patent assignees and their accumulated patent stock over the period 1978-2001 (EPO patent applications), we

identified all private firms that have developed technological activities in the field of biotechnology during that period. The selected parent firms are active in different sectors: mostly in the biotechnology, pharmaceutical or chemical industry but the list of parent firms also includes producers of consumer products, energy concerns and breweries. For consistency of our sample, we only retain the biopharmaceutical firms. Due to missing financial data on firm controls and/ or incomplete information on the group structure of parent firms, the list of firms was further reduced to 59 biopharmaceutical firms. All these firms have headquarters in the United States, Europe (EU-15) or Japan. Appendix 1 contains a complete list of the firms under study.

For this sample of 59 biopharmaceutical firms, we collected patent data at the consolidated parent level, i.e. comprising headquarters and all (majority-owned) subsidiaries of the parent firm for the period 1995 to 2002. This consolidation process implies the mapping of all changes in the group structure of the 59 parent firms due to acquisitions, mergers, green-field investments and spin-offs. For this purpose, yearly lists of subsidiaries included in annual reports, yearly 10-K reports filed with the SEC in the US and, for Japanese firms, information on foreign subsidiaries published by Toyo Keizai in the yearly Directories of Japanese Overseas Investments, are used. Constructing ‘consolidated’ patent portfolios is important since on average 20 percent of the parent firms’ patents are not applied under the (current) name of the parent firm. Firm financial data are also collected at the consolidated level through corporate annual reports and Worldscope and Compustat financial databases.

### **Biotechnology R&D Clusters**

Biotechnology is a knowledge-intensive technology field, which from its origin has developed within a limited number of regions of excellence, such as California or the Boston area (United States) and Cambridge (United Kingdom). To identify biotechnology R&D clusters worldwide, we use the dataset with all EPO patent applications in the field of biotechnology retrieved by Glänzel et al. (2004). The dataset of EPO patents shows that, for the period 1990-1999, most of patenting activity in the domain of biotechnology (94%) takes place in the United States,

Europe (EU-15 and Switzerland) and Japan. In this study, we therefore focus on regions in the United States, Europe and Japan<sup>10</sup>.

More specifically, we will focus our study on the following national subdivisions: European (EU-15 and Switzerland) NUTS 2 regions (n=220), US states (n=50), and Japanese prefectures (n=47). The NUTS classification<sup>11</sup> provides a breakdown of European countries into regions, primarily based on institutional divisions currently in force in the country. The limits of the regions are fixed according to population size. For the NUTS2 level, minimum and maximum thresholds for the average size of the regions are respectively 800.000 and 3 million. The United States of America consist of 50 sub-national entities called states, having their own state government with substantial state responsibilities. The population in the US states varies from 500,000 to 36 million, with the majority of the states falling between the threshold values for the European NUTS2 regions. The prefectures of Japan are the country's 47 sub-national jurisdictions with an own governor and parliament. The sizes of these prefectures vary between 600,000 and 12 million inhabitants. It can be noted that cluster boundaries do not necessarily coincide with the boundaries of administrative regions. They may well spread over more than 1 region (e.g. the tri-state cluster in the states of New York, New Jersey and Pennsylvania and the cluster covering the prefectures of Tokyo and Kanagawa). Alternatively, regions may enclose more than one cluster (e.g. the triangle San Francisco - San Jose - Sacramento, better know as Silicon Valley, and the region between Los Angeles and San Diego in the state of California). Despite these concerns, we opted for an analysis of regions coinciding with the boundaries of the administrative subdivisions (US states, European NUTS 2 regions and Japanese prefectures)<sup>12</sup>. Although the selected regions in the US, Europe and Japan are heterogeneous in terms of population<sup>13</sup>, we believe that they provide consistent, comparable units of analysis as they reflect areas for which an administrative authority has power to take administrative or policy decisions.

To measure the amount of biotechnology R&D activity in a region, we calculate the total number of EPO patent applications of a region for the period 1990-1999. Patent applications are allocated to regions in the United States, Europe (EU-15 and Switzerland) and Japan based on address information of the inventors. In case a patent contains multiple inventors in different regions, the patent is fully counted in each region. Allocation based on inventor addresses is the most commonly used

approach in patent studies since – especially for large firms - allocation based on assignee addresses might signal the location of corporate headquarters rather than research laboratory where the invention took place (DEYLE and GRUPP, 2005).

The resulting dataset allows us to rank all 317 US, European and Japanese regions in terms of their total technological performance in the field of biotechnology over the period 1990-1999. We define a region as a R&D biotechnology cluster if it contains at least 1.5% of the total number of US, European and Japanese EPO patent applications in the field of biotechnology. This definition results in a list of 10 regions which account for almost 70% of all biotechnology patents (see table 1). Most biotechnology R&D clusters are located in the United States, with a clear supremacy of the state of California, which in itself account for almost 11% of all observed biotechnology patents. Europe counts 7 top regions, located in Denmark (region of Copenhagen-Bagsvaerd), France (region of Paris), Germany (region of Munich and region of Frankfurt Am Main–Darmstadt-Wiesbaden), the Netherlands (region of Leiden-Rotterdam-Den Haag) and United Kingdom (Cambridgeshire, Oxfordshire, Berkshire and Buckinghamshire). With Tokyo, Kanagawa and Osaka, Japan has three top regions in biotechnology.

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Insert Table 1 about here  
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### **Firm Variables and Model**

Our panel of 59 biopharmaceutical firms enables us to investigate whether presence in biotechnology R&D clusters affects firms’ overall technological performance. The dependent variable is the yearly number of EPO patent applications of a firm in biotechnology (using the search key of GLÄNZEL et al. (2004) to identify biotechnology patents). Since the dependent variable takes only non-negative integer values, a negative binomial model is applied. To control for the impact of unobserved firm-specific characteristics on firms’ overall technological performance, we opt for a fixed effects estimation technique.

To identify the regions in which a firm is present, we rely on inventor address information of the biotechnology patents applied for by the firm over the past two years. More specifically, a firm – consisting of the parent firm and its subsidiaries - is considered to have undertaken biotechnology R&D activities in a region if the firm

has at least two inventors residing in that region during the last two years. Given the fact that R&D collaboration is quite widespread in the field of biotechnology, we decided to consider presence in a region only on the *fully owned patents*, thus reflecting the number of regions (clusters and other regions) in which a firm is present through its fully owned or single parent patents, i.e. technologies developed or acquired by the firm<sup>14</sup>. We construct two indicators related to the location of the biotechnology R&D activities of a firm: (i) *clusters*, reflecting the number of R&D biotechnology clusters in which a firm is present and (ii) *other regions*, reflecting the number of other regions, not defined as clusters, in which a firm undertakes R&D activities<sup>15</sup>. To test for non-linear relationships between the R&D location variables and the firm's overall technological performance, both linear and squared terms of the location variables are included in the empirical models. Applying a fixed effect model requires that there is enough within-firm variation over time with respect to the R&D location variables. Over the time span 1995-2002, all 59 firms in our sample vary in terms of the total number of regions and the total number of clusters in which they are present, but for a number of firms the presence in clusters remains fairly stable over time. Therefore, we also present the results of the random effect models.

Several other variables that might have an impact on a firms' overall technological performance are added to our empirical model. A first control variable is the size of a firm's *biotechnology patent portfolio*. This portfolio consists of the total number of patents in the field of biotechnology applied for by the firm in the past 5 years. In line with COHEN and LEVINTHAL (1990), we expect that the cumulative internal R&D capabilities of a firm increase the firm's capacity to absorb external knowledge. Therefore, we expect this variable to impact positively on a firm's technological performance. Further, we also control for firm differences in total R&D expenses<sup>16</sup>. This variable is collected through corporate annual reports, Worldscope and Compustat financial databases, and is one-year lagged in the analyses. Finally, we include year dummies (1995 as base category) to account for time-specific factors affecting the number of firm patent applications.

Table 2 provides descriptive statistics of the biopharmaceutical firms in our dataset. This table shows that the average firm in our sample applies for 14 biotechnology patents per year and has average R&D expenditures of 452 mio USD. Table 2 further reveals that the biopharmaceutical firms in our sample are – on average - present in 2.05 clusters and 2.13 other regions.

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### ***Empirical results***

Using a negative binomial model, we test whether being present in R&D biotechnology clusters has an impact on firms' overall technological performance in the field of biotechnology. The results are presented in table 3 and table 4. We present both the random and the fixed effect models. Random effect models consider the variation across firms, while fixed effect models only take into account the variations within firms. As such, the fixed effect model is a special case of a random effect model which allows controlling for unobserved firm-specific effects.

Model 1 (table 3) is a random effect model including the control variables and the *regions* variables (linear and squared term), where the regions variables indicate the total number of regions in which a firm develops its R&D activities. Both the lagged biotech patent portfolio and the R&D expenditure variables are positive and significant. The linear and squared term of the regions variable respectively have a significant positive and negative coefficient. This result provides empirical evidence that firms present in multiple regions gain additional benefits in terms of technology performance albeit of a diminishing nature (inverted U-shaped relationship). In a next step, we repeat the analyses with a fixed effect model, taking into account unobserved firm-specific effects. The regression results in model 2 confirm the inverted U-shaped relationship between the total number of regions in which a firm is present and the firm's subsequent technological performance.

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Insert Table 3 about here  
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In table 4, we investigate whether a distinctive effect from R&D clusters can be found. Model 3 is a random effect model including the linear and squared term of the *clusters* variable and the linear term and the squared term of the *other regions* variable. The results reveal that both the linear and squared cluster variables are significant, while the *other regions* variables are not significant. For the clusters variables we find an inverted U-relationship between the total number of clusters in which the firm is present and its subsequent technological performance. These results

seem to confirm our hypotheses that presence in multiple R&D clusters and not merely the presence in other regions is contributing to the overall technological performance of firms. In model 4, the results of the fixed effect model is presented. Again, this model confirms the inverted U-shaped relationship between R&D clusters and technological performance of the firm. Similar to the results in model 3, the other regions variables are not significant. The coefficients of the cluster variables in model 4 indicate that biopharmaceutical firm should – ideally – be present in 3.46 biotechnology clusters. Since the average biopharmaceutical firm in our sample is present in 2.02 biotech clusters, most firms can still improve their technological performance by being present in more biotech R&D clusters. Model 4 also indicate that the marginal effect from being present in an additional region is more than three times as large for biotech clusters (0.1219) as compared to other regions (0.0374). Together, the results in table 4 suggest that biopharmaceutical firms can enhance their technology performance by being present in multiple R&D clusters. In addition, we can conclude that being present in multiple R&D clusters and not the mere presence in multiple locations, is contributing to the overall technological performance of the firm.

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### ***Conclusions, limitations and directions for future research***

Firms active in knowledge-intensive technology fields such as biotechnology, are increasingly developing global R&D activities, with location choices for an important degree being determined by the technological capabilities present in a region. Agglomeration externalities present in technology clusters, such as the access to a highly-skilled pool of labor and specialized suppliers, and the occurrence of localized knowledge spillovers are expected to increase the productivity and enhance the innovative performance of firms located in such regions.

In this study, we identified 20 leading clusters in the field of biotechnology on a worldwide scope based on the cumulative number of patents (EPO) applied for by firms and other innovation actors during the period 1990-1999. Next, building on a panel data set of 59 consolidated biopharmaceutical firms (time period 1995-2002), we examine whether being present in multiple biotechnology R&D clusters has a

positive impact on the overall technological performance of firms active in the field of biotechnology. Our study provides evidence for an inverted U-relationship between the number of R&D clusters in which a firm is present and its subsequent overall technological performance. Our results further reveal that this cluster effect is distinctive from a mere multi-location effect.

The findings of our study suggest that in knowledge-intensive fields, firms can enhance their overall technological performance by developing R&D activities in *clusters* that host a considerable level of technological activity within the same field. The results also reveal that boundaries exist in terms of the net beneficial effects of spreading R&D activities over locations. When the number of clusters in which a firm is carrying out R&D activities exceeds a certain optimum, increasing costs in terms of coordinating and integrating geographically dispersed R&D units might start to prevail over the marginal benefits from getting access to new, relevant knowledge through localised spillovers. At the same time, the observed diminishing effects might also be caused by insufficient critical mass in terms of technological activity when R&D activities become further dispersed. Distinguishing between both potential drivers of the observed declining effect of cluster membership might be an interesting area for further research. Within this study, we focused on regional technological capabilities within the same field (biotechnology); as such, a natural extension of the research reported here implies an examination of ‘Jacobs’ externalities as well: to what extent are positive effects to be observed stemming from regional capabilities situated within different (related) technological fields? Finally, within this analysis we treated the micro-dynamics underlying the observed positive technological performance effects as a ‘black box’. While our findings are interesting within the framework of R&D location decisions, identifying the most effective mechanisms (e.g. collaboration with local firms and/or research institutes, technology acquisition, researcher mobility,...) to benefit from knowledge present in R&D clusters might be highly relevant to ensure that firms actually do yield results once location decisions have been made. We do hope that our analysis and findings inspire colleagues to engage in such endeavours.

## **Appendix 1: List of biopharmaceutical firms**

Abbott Laboratories	Innogenetics
Affymetrix Inc.	Invitrogen
Ajinomoto	Isis Pharmaceuticals Inc
Amgen	Johnson Johnson
Applera	Kyowa Hakko Kogyo
Astrazeneca	Lonza Ag
Aventis	Martek Biosciences
Beckman Coulter	Maxygen Inc
Becton Dickinson And Company	Merck Co
Biogen Idec	Merck Kgaa
Boehringer Ingelheim	Millennium Pharmaceuticals
Bristol Myers Squibb	Mochida Pharmaceutical
Cell Genesys Inc	Myriad Genetics Inc
Chiron	Nanogen Inc
Diversa Corp	Novartis
Eli Lilly	Novo Nordisk As
Fujisawa Pharmaceutical	Pfizer
Gen Probe Inc	Regeneron Pharmaceuticals
Genelabs	Ribozyme Pharmaceuticals
Genencor	Schering
Genentech Inc	Schering Plough
Genzyme	Scios Inc
Geron Corp	Seikagaku
Gilead Sciences	Sequenom Inc
Heska Ag	Shionogi
Human Genome Sciences	Solexa
Hybridon	Tanox Inc
Icos Corporation	Transgene
Idexx Laboratories	Wyeth
Incyte Corporation	

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<sup>1</sup> JACOBS (1969) argued that the flow of complementary knowledge between firms active in *different* industries might play a more important role than within-industry knowledge flows. She therefore believes –in contrast to MARSHALL (1920), ARROW (1962) and ROMER (1986)- that a variety and diversity of geographically concentrated industries is most beneficial to stimulate regional innovation and growth. In this study, we only focus on MAR (Marshall–Arrow-Romer) externalities.

<sup>2</sup> Some studies (ex. HILL and NAROFF 1984 and SWANN and PREVEZER 1996) have also studied the impact of cluster location of the financial performance and growth of firms.

<sup>3</sup> Clusters are further delineated by using a time-distance (by car) of 15 minutes from the major knowledge institutes.

<sup>4</sup> Regions encompassing a city that produces more than 5000 life science articles are considered as “life science” regions

<sup>5</sup> Note that studies of BAPTISTA and SWANN (1998) and BEAUDRY and BRESCHI (2003) do have time series, but they use pooled cross-sectional data controlling to a limited extent for firm heterogeneity by including the pre-sample innovative performance of the firms. Similarly, FURMAN et al. (2006) has panel data, but does not include firm fixed effect in their model.

<sup>6</sup> As the geographic distribution of research in a specific therapeutic class changes only to a very limited extent during the period covered by the study, results including firm random or firm fixed effect are not robust.

<sup>7</sup> The lag between application and granting decisions appears to be much larger for the field of biotechnology than for other fields. We calculated that 75% of the EPO patent applications in 1995 were granted within the next 6 years. For patent applications in the field of biotechnology only 40% of the patent applications were granted over a time period of 6 years.

<sup>8</sup> Random effect models with a US dummy reveal that there is no distinctive effect for firms with headquarters in the United States.

<sup>9</sup> GLÄNZEL et al. (2004) defined and validated a search key to retrieve all EPO patents in the biotechnology domain in the period 1978-2001.

<sup>10</sup> Note that no other region outside the United States, Europe (EU-15), Switzerland and Japan has sufficient patent applications to qualify as a cluster.

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<sup>11</sup> NUTS stands for Nomenclature of Territorial Units for Statistics and is the three-level hierarchical classification of regions established by Eurostat.

<sup>12</sup> Analyses in which we combine administrative subdivisions in order to better follow the actual boundaries of biotechnology clusters, yield similar results.

<sup>13</sup> Note that also within the same country administrative divisions and subdivision are heterogeneous in terms of size.

<sup>14</sup> Co-owned patents, i.e. patents with multiple assignees from different parent organizations, were excluded from our analyses. However, including them provides similar results.

<sup>15</sup> Alternatively, one could include the weighting of a cluster (total number of patent applications in a cluster in a certain year) instead of a simple count of presence (0/1) in a cluster. Such models yield similar results as the ones reported in this paper.

<sup>16</sup> Firm level R&D expenses specifically related to biotechnology activities are not available.

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## Tables

**Table 1 Top Biotechnology R&D clusters**

	<b>Region</b>	<b>Country</b>	<b>Patents</b>	<b>%</b>	<b>Cum %</b>
1	California	United States	4,162	15.4%	15.4%
2	Massachusetts	United States	1,853	6.8%	22.2%
3	Maryland	United States	1,285	4.7%	27.0%
4	Pennsylvania	United States	1,264	4.7%	31.7%
5	New York	United States	1,072	4.0%	35.6%
6	New Jersey	United States	1,005	3.7%	39.3%
7	Tokyo	Japan	916	3.4%	42.7%
8	Île de France	France	873	3.2%	45.9%
9	Kanagawa	Japan	724	2.7%	48.6%
10	Osaka	Japan	672	2.5%	51.1%
11	Denmark	Denmark	643	2.4%	53.5%
12	Washington	United States	619	2.3%	55.8%
13	Oberbayern	Germany	593	2.2%	58.0%
14	Illinois	United States	473	1.7%	59.7%
15	East Anglia	United Kingdom	463	1.7%	61.4%
16	Texas	United States	446	1.6%	63.1%
17	Darmstadt	Germany	443	1.6%	64.7%
18	Berkshire, Buckinghamshire and Oxfordshire	United Kingdom	434	1.6%	66.3%
19	North Carolina	United States	416	1.5%	67.9%
20	Zuid-Holland	Netherlands	410	1.5%	69.4%

**Table 2 Descriptive statistics**

	Obs	Mean	Std. Dev.	Biotech patents	Biotech portfolio	R&D	Clusters	Other regions
Biotech patents	422	14.17	18.57	1				
Biotech portfolio	422	26.24	31.87	0.7526	1			
R&D Expenditures (in thousands USD)	422	452,396	760,283	0.2849	0.3607	1		
Number of clusters in which present	422	2.05	1.81	0.4053	0.549	0.4533	1	
Number of other regions in which present	422	2.13	2.91	0.3125	0.4372	0.5184	0.4490	1

**Table 3 Negative Binomial Regression:  
Number of Biotech Patents acting as a dependent variable**

	<b>Model 1</b>	<b>Model 2</b>
	<b>Firm</b>	<b>Firm</b>
	<b>Random Effect</b>	<b>Fixed Effect</b>
Biotech patent portfolio (2 year)	0.0055*** (0.0012)	0.0038*** (0.0013)
R&D Expenditures	0.0003*** (0.0001)	0.0003*** (0.0001)
Number of regions in which present	0.0784*** (0.0227)	0.0558** (0.0245)
Number of regions in which present <sup>2</sup>	- 0.0024*** (0.0009)	- 0.0018* (0.0010)
Time dummies	Y	y
_cons	0.4794 (0.1702)	0.6284 (0.1676)
N	59.00	59
Loglikelihood	-1337.01	-1025.15
chi2	136.37	83.95
p	0.0000	0.0000

Symbols \*, \*\*, \*\*\* beside parameter estimate indicate, respectively, statistical significance at the 10%, 5% and 1% levels.

**Table 4 Negative Binomial Regression:  
Number of Biotech Patents acting as a dependent variable**

	<b>Model 3</b>	<b>Model 4</b>
	<b>Firm</b>	<b>Firm</b>
	<b>Random Effect</b>	<b>Fixed Effect</b>
Biotech patent portfolio (2 year)	0.0059*** (0.0012)	0.0043*** (0.0012)
R&D Expenditures	0.0003*** (0.0001)	0.0003*** (0.0001)
Number of clusters in which present	0.1726*** (0.0566)	0.1219** (0.0589)
Number of clusters in which present <sup>2</sup>	- 0.0197*** (0.0067)	- 0.0176** (0.0071)
Number of other regions in which present	0.0442 (0.0294)	0.0374 (0.0327)
Number of other regions in which present <sup>2</sup>	- 0.0015	- 0.0010