Knowledge capital in biotechnology industry: impacts on Canadian firm performance

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Abstract: Knowledge has become the main driver of economic growth. This is true both at the level of the macro-economy, where emerging countries make efforts to capture knowledge from more advanced countries and at the level of the firm, as companies make efforts to acquire complementary knowledge from other firms. The specific types of knowledge associated with performance differ from one industry to another, and on company maturity. A number of studies demonstrated that biotechnology performance and the geographical concentration of US firms are related to the recruitment of star researchers. This paper confirms these results for Canadian companies and goes further in accounting for the specific roles played by these highly productive university researchers and their impact on the performance of biotechnology enterprises. This discovery points to a new stage in the birth of biotechnology companies, and is associated with the selection of venture capitalists and major pharmaceutical companies who finance these specialised biotechnology firms.

Keywords: academic entrepreneurship; biotechnology; bioscientists; geography of innovation; localised knowledge spillovers; Canada.

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1 Introduction

The rise of the knowledge economy involves multiple interrelated changes, including the regional distribution of the economic activity, the frontiers of the firm, as well as the relative importance of human capital. First economic activity tends to concentrate in regions where knowledge is produced. Firms tend to locate their R&D activities in knowledge producing regions, thus, producing virtuous circles of growth for such agglomerations (Dunning, 2002; Maskell, 2001). Also, the frontiers of the firm become more porous as the number of technology alliances multiplies, as firms seek to cooperate through strategic alliances in order to produce new knowledge or to seek complementary knowledge (Grant and Baden-Fuller, 2004). Also, the most successful developing countries put forward strategies that allow them to attract knowledge-intensive activities by investing in human capital and revamping their knowledge-producing institutions (Finegold et al., 2004).

The understanding and measurement of the knowledge assets of the firm have travelled a long way in the last decade (Boisot, 1998, Bontis, 2001; Teece, 2003). From the simple count of human capital authors have incorporated competence, culture, knowledge management and producing routines, and patents, to name a few. Management science has also improved our understanding of the sources of knowledge, internal and external, and the processes through which such knowledge is absorbed and used (Fey and Birkinshaw, 2005).

Knowledge, thus, is more than ever the force driving economic growth, leading to ever-closer ties between science and technology (Buigues, 2000, Freeman, 1982; Gibbons et al., 1994). In particular, much of the technological change in biotechnology depends on the efforts put into exploiting new scientific and technological discoveries. Moreover, these inventions turn into commercial applications more rapidly than in the past, which is why biotechnology enterprises are forming ties with universities and government research institutes. This constitutes the basis for a new innovation structure bringing basic and applied research closer to development (Etzkowitz, 2008; Etzkowitz and Webster, 1994). As a result, technology companies based on scientific discoveries sometimes succeed in growing according to specific criteria. Indeed, just a few factors seem to account for biotechnology-firm performance during the 1990s, specifically patent ownership, venture capital, expansion into export markets, and strategic alliances with multinationals (Niosi, 2003; Niosi and Bas, 2001). Zucker et al. (1998) had identified another performance determinant, namely star-scientist ties with US biotechnology firms. These star scientists, who have made major biotechnology discoveries, prefer to enter into contracts with existing firms or launch their own biotechnology company in the same region instead of turning over their research to their university or a government research institute.

Initially, we worked with the definition and hypothesis proposed by Zucker et al. (1994, 1995, 1998, 2002) for star scientists, that Zucker et al. defined those who publish actively genetic sequences. Yet, because past research demonstrated the importance of patents (Griliches, 1990; Hagedoorn and Cloodt, 2003, Niosi, 2003), we also searched for information about all US patents assigned to Canadian biotechnology firms in order to identify the associated scientists and the types of relations involved.

2 Theoretical background

In biotechnology, the performance of firms and that of innovative regions are linked. High-tech growing firms are generally located in areas hosting important strategic factors (such as a pool of highly specialised human capital, high-quality research institutes and universities, and venture capital funding). These elements enable stellar firms to survive and prosper.

2.1 Localised knowledge spillovers from star researchers to biotechnology firms

Over the last 15 years, economists and other social scientists have become keenly interested in the geography of innovation, leading them to analyse spatial aspects (such as geographical proximity) of knowledge spillovers. It has become evident that innovation sources do not lie exclusively within company boundaries. New ideas are not necessarily traded in the markets and are not produced only as the result of interactions between scientists working within a company. Indeed, they also arise from relations between high-tech firms, users and scientists in universities and government laboratories (Bessant and Tidd, 2007; Powell, 1998). In many high-technology sectors, we are now witnessing close connections between the integration of the discovery, use, and production of new knowledge from different sources (Gibbons et al., 1994).

As a result, the effects of knowledge spillover can be defined by the scientific and technological externalities of a few individuals who invested in technological research and development. They will eventually facilitate the efforts of other agents of innovation. Based on this definition, the effects of localised knowledge spillovers can be defined by the knowledge externalities that enable firms located in the proximity to important knowledge sources (such as universities and government research institutes) to introduce innovations more rapidly than companies hosted by other locations. To begin with, universities are mainly responsible for the localised diffusion of biotechnology knowledge. In other words, the effects of knowledge spillover occur locally because the geographic proximity of academic researchers facilitates knowledge transmission to the private sector via commercialisation initiatives (patents and licenses), scientific parks, and the flow of graduate students into the labour market (Saxenian, 2005).

Several analysts have examined localised relations pertaining to scientific patenting in industry and academia, the mobility of R&D staffs of firms and universities, and company innovation rates (see Acs et al., 1992; Anselin et al., 1997; Audretsch and Feldman, 1996; Chesbrough et al., 2006; Feldman, 1994, 1999; Griliches, 1992; Jaffe, 1986, 1989; Jaffe et al., 1993; Zucker et al., 1994, 1995, 1998, 2002). The starting point of the studies is the high geographical concentration of innovation activities. Consequently, the firms located in areas of major and intense R&D flow in the public and private sectors, as well as a high rate of academic research, tend to be more innovative than companies elsewhere because they take advantage of the knowledge spillover from these sources.

Business literature argues that the number of patents is an appropriate indicator for comparing the innovation performances of companies in terms of new technologies, processes, and products (Cassiman et al., 2008; Gittelman, 2008). Even the strongest critics of the general use of patents as performance indicators (Arundel and Kabla, 1998; Mansfield, 1991) admit that patents could represent appropriate indicators in many high-technology sectors. Consequently, the identification of the inventors listed in patents provides key information on the history of R&D processes related to a technical invention and thus, a means for retracing knowledge flow through innovation systems or regional clusters of firms.

Yet, a growing number of researchers use patent citations as indicators of the R&D output of firms, or as determinants of innovation performance that could impact on their growth. Unlike a simple counting of patents, which is purely quantitative, patent citations also include a measurement of patent quality because there appears to be a positive relation between a patent's importance and the number of times that it is cited. Patent citations can be very useful as indicators of a patent quality in economic studies of biotechnology-firm innovation and performance (Jaffe and Trajtenberg, 2002).

To summarise, the microeconomic analysis of technological change processes involves references to various measurements of intellectual or knowledge capital. Patents and patent citations are indicators determining the output from investments into new knowledge and technologies. As a result, the number and composition of citations that a patent receives from subsequent patents represent determinants of the technological and economic impact of the invention in the patent. Technological performance can be defined in terms of the firm's achievements measured by their research capacities and their R&D inputs (patents and patent citations). Similarly, Hagedoorn and Cloodt (2003) put forward the idea that it is better to use several indicators to measure innovation impact on a firm's performance in high-technology sectors. Ideally, R&D inputs such as R&D expenditures, number of patents, patent citations, and the announcement of new products should be combined to get a better idea of innovation impact on the firm's performance.

2.2 Movement of scientists

Other studies have focused more on the movement of scientists, since knowledge travels with them. In a study dealing with the linkages between academic scientists and biotechnology firms, Audretsch and Stephan (1999) found that geographic proximity matters but is not always important in these knowledge-based relations. Their findings demonstrate that a large percentage (70%) of these links is not local. The interactions take on a more local character when a university researcher becomes genuinely involved in creating a biotechnology enterprise. In contrast, when the patent is the sole link between the firm and the researcher, the firm is often located outside of the region where the researcher works.

Zucker and Darby (1995) focused on star scientists in order to measure the impact of innovation import on the overall performance of biotechnology firms. The authors found that the geographic distribution of star researchers plays a determining role in firms becoming involved in biotechnology. In operational terms, Zucker and Darby define a star scientist as one who has discovered and published more than 40 gene sequences over a five-year reference period (1990–1994), such as compiled in GenBank. Consequently, Zucker and Darby established that a region such as the San Francisco Bay Area produces a significant amount of biotechnology research and, by that very fact, hosts a large cluster of biotechnology firms. Yet, their work provides no indication of the degree to which biotechnology firms, once created and located in an area; establish networks with scientists in geographic proximity. The implicit hypothesis is that networks remain ineluctably local. Also, genetic sequencing has known exponential growth in the last ten years thanks to new computational methods, and sequencing does not distinguish star scientists from graduate students or lab technicians any more. If the general hypothesis relating the presence of star scientists to firm's performance remains useful, the definition of star needed to be updated.

The standard notion about the effects of localised knowledge spillovers, based on the idea that university-based scientists are engaged in disinterested, purely basic research, may not apply to biotechnology (Zucker et al., 1998). The interactions between researchers and firms in this field appear to be more the result of commercial and non-commercial transactions than simply the result of knowledge spillovers. Indeed, scientific entrepreneurs capitalise on discoveries when they are working in a university or a government laboratory.

The literature on endogenous growth assumes that technology is public property that is costly to discover but easy to imitate. Yet, in several areas of high technology, knowledge has natural excludability. In other words, the tacit nature of acquiring knowledge requires face-to-face contact. As a result, radical technologies – such as biotechnology – tend to be perceived as rival knowledge capital and are very difficult to codify. This being said, it appears that the literature on endogenous growth starts to shift away from the theory of the firm's analysis unit and turn towards understanding what motivates scientists to report their discoveries, to create new enterprises, or to cooperate with existing firms to commercialise their discoveries.

In spite of the growing importance of the effects of knowledge spillovers in the literature on innovation, there is no consensus on how or why they occur. According to Breschi and Lissoni (2001), few authors have explored these avenues. An in-depth examination is required of the various mechanisms used by biotechnology firms to acquire knowledge, that is, the commercial and non-commercial transactions by which knowledge can be exchanged between university-based researchers, government research institutions and companies.

If the most recent biotechnology discoveries typically lie in the minds of several scientists, and are diffused through practice and face-to-face exposure, the simple analysis of the effects of knowledge spillovers is less than perfect. Therefore, the specific links of the researchers to the biotechnologies must be identified.

2.3 The hypotheses

Several hypotheses can be inferred from the discussion above. They are equally related to the cluster phenomenon in biotechnology and to the growing impact of bioscientists (any researcher active in biotechnology) as economic agents and suppliers of specific competencies to biotechnology firms.

H1 Biotechnology firms tend to cluster in areas where there are bioscientists.

In the USA, biotechnology firms and star scientists tend to aggregate in high numbers in the proximity of universities. The creation and location of new biotechnology enterprises can be explained, first of all, by the presence of scientists actively contributing to research breakthroughs (Zucker et al., 1994, 1995, 1998). More specifically, their output accounts for the geographic localisation of biotechnology knowledge. Nevertheless, the effects of university knowledge spillover on the research and development productivity of nearby biotechnology firms are highly concentrated in certain firms with ties to the star scientists, and practically inexistent in others. Moreover, affiliated star scientists start up their firms in the same area as their universities (Audretsch and Feldman, 1996; Audretsch and Stephan 1999; Zucker et al., 1994, 1995, 1998). In this study, we will show that the same phenomenon of clustering of bioscientists and biotechnology firms takes place in Canada.

H2 Biotechnology enterprises with ties to star bioscientists perform better than those without.

In their study on the impact of star scientists on the performance of US biotechnology firms, Zucker et al. (1994, 1995, 1998) found that university-based researchers who made major genetic-sequence discoveries and who had ties to biotechnology firms had a major impact on their performance. In their work, firm performance is measured as an increase in the number of employees during the study period.

Yet several more recent Canadian studies have shown that patents – much more than genetic-sequence discoveries – are related to the performance of biotechnology firms in areas active in the discipline (Niosi and Banik, 2005; Niosi and Bas, 2003; Raoub et al., 2003). This accounts for our decision to create our own typology of bioscientists based on mainly on patents, and secondarily on scientific publications, and genetic-sequence discoveries. Table 1 summarises this typology. Also, venture capital has become more selective in the area of biotechnology and looks for high-tech firms with landmark patents, and not simply patents.

Table 1 Typology of Bioscientists

1a	Bio-superstars: five patents and >one publication per year
1b	Bio-stars: two to four patents and >= one publication per year
2a	Bio-collaborators type A: one patent per year and < one publication per year
2b	Bio-collaborators type B: one patent per year or >= one publication per year

The following hypotheses deal with measuring the impact of bioscientist knowledge capital on the performance of biotechnology firms. In other words, this analysis will yield indicators of the importance of knowledge resources as a sustained competitive edge for biotechnology firms. Moreover, these hypotheses will shed some light on the types of bioscientists who have the greatest influence on the internal performance of biotechnology firms.

H2a: Interactions with bioscientists having been granted cited patents are positively correlated with firm growth.

3 Canadian biotechnology industry study

Recent statistics[1] show that some Canadian biotechnology companies are experiencing unprecedented growth. They are exporting their products and providing innovative, highly specialised jobs. According to the Statistics Canada survey, there were 375 biotechnology firms in Canada in 2001, generating sales of C$3.8 billion. In 2005, there were 532 firms generating revenues of C$4.2 billion, and spending 1.7 billion in R&D. The vast majority of these companies were involved in the development of products and processes for human health. Moreover, most Canadian biotechnology firms are private companies and not listed on stock exchanges. Only 17%, some 86 firms were public companies. More than 70% of these dedicated biotechnology firms were located in Quebec, Ontario and British Columbia. Some 75% of them are small companies (50 or fewer employees), and only 10% are large companies (151 or more employees) (Statistics Canada, 2007).

In order to have a profile of Canadian biotechnology firms and their performance, we began by collecting data on a large population of biotechnology companies established in Canada, based on the Canadian Biotechnology Directory. For the database on biotechnology enterprises, we collected all key information about private and public companies involved in human health.[2] Past studies have demonstrated that these firms account for almost all of the growth (Niosi, 2003). This decision was also motivated by the fact that 70% of biotechnology firms are active in this field.

A database on bioscientists was also created in order to measure their specific ties to biotechnology firms, as well as certain aspects of their outputs (patents and publications). We drew on many data sources to build this enormous database. Our research began by initially identifying the presidents, chief executive officers and other managers in the identified biotechnology firms working on human health. This enabled us to build a database of researchers active in biotechnology with patents, genetic-sequence discoveries, and scientific publications. We even retained the data for researchers with at least a single genetic-sequence discovery linked to a biotechnology firm, in an effort to test both the hypotheses of Zucker et al. (1994, 1998) on the geography of innovation and performance, and their definition of a star scientist.

This study tests these hypotheses by constructing a sample of 150 human-health biotechnology firms and 442 bioscientists with identifiable links to these firms. The geographic distribution of biotechnology firms and of their patents IS provided according to census metropolitan area (CMA).

We also developed a detailed breakdown of bioscientists involved in economic development into three distinct profiles according to census metropolitan area:

Profile 1 linked (connected to a biotechnology firm as the co-inventor or co-author of a patent or scientific publication)

Profile 2 affiliated (connected to a biotechnology firm as part of its senior management)

Profile 3 associated (connected to a biotechnology firm as part of senior management and belonging to a Canadian university or government research laboratory).

The statistical methods used include univariate analysis, correlations, and multiple linear regression analysis. We use the employment variation between 1997 and 2002 as the main dependent variable. The major goal of this research was to assess the influence of groups of researchers on the performance of biotechnology firms. By measuring the relations of association, we construct an exploratory model of the impact of bioscientists on the performance of biotechnology firms. The other important objective, stated in hypothesis 1, is to determine if the clustering of biotechnology firms in census metropolitan areas can be accounted for by the presence of bioscientists.

3.1 *The sample population*

The sample consists of 150 biotechnology firms in the human-health field (nearly 57% of the 262 biotechnology firms inventoried by Statistics Canada are involved in human-health biotechnology and 442 bioscientists have ties to these firms). The median age is seven years, and only three firms are more than 20 years old. The median number of employees was 20 in 1997 and 25 in 2002. At the time of the study, 69.3% of the biotechnology firms in our sample experienced a variation in employment between 1997 and 2002. In fact, only 52% of firms showed a positive variation in the number of jobs created. Of these, the median variation was ten jobs between 1997 and 2002.

In 2002, the biotechnology firms studied held a total of 550 US patents. The average number of patents per firm in 2002 was 3.65; 66 biotechnology firms held no patents. The bioscientists affiliated with or linked to biotechnology firms discovered 45340 genetic sequences. Furthermore, we inventoried patent citations for the biotechnology firms. The total number of patent citations in 2002 was 356, or an average of 2.36 patent citations per firm.

As for bioscientist typology, based on Table 1, the median number of bioscientist is two per technology firm. Table 2 and Table 3 provide details on the number of bioscientists according to type and specific profile for each of Canada's CMA.

Table 2 SBFs by Canadian CMA in 2002

CMA	*CMA census population*	*# SBFs*	*# Normalised SBFs**	*# SBF patents*	*# Normalised SBF patents**
Montreal	3,426,350	47	23	113	50
Toronto	4,682,897	32	11	130	42
Vancouver	1,986,965	30	25	123	94
Edmonton	937,845	12	21	31	50
Quebec City	682,757	11	*27*	*64*	*142*
Ottawa	1,063,664	7	11	15	21
London	432,451	5	20	11	40
Calgary	951,395	4	7	47	75
Winnipeg	671,274	2	5	16	36
Total	14,835,598	150	150	550	550
Average	1,648,400		17		61

Notes: # Normalised SBFs*: number of SBFs based on the latest census population.
Normalised SBF patents*: number of assignee patents to Canadian SBFs based on the latest Census CMA population.

Source: Statistics Canada (2002b) and Thomson Bioscan (2002)

3.2 Descriptive results

The distribution of biotechnology firms throughout Canada's CMAs reveals dense clusters in the major metropolitan areas of Montreal, Toronto, and Vancouver: 72% of Canada's biotechnology firms are located in these three CMAs (see Table 2). However, when the population of each CMA is taken into consideration, two smaller metropolitan agglomerations appeared to be very fertile ground for the development of biotechnology firms: Quebec and Edmonton. From this perspective, Toronto, the largest CMA, appears much less active. Nevertheless, we note that Canadian biotechnology firms appear and develop around universities and government research centres in medium-sized and larger CMAs.

Table 3 Number of bioscientists and their association with SBFs by Canadian CMA in 2002

CMA	*#Scientists*	*Bioscientist model*	*# by profile association*
		1a 1b 2a 2b	*1* 2* 3**
Vancouver	118	19 50 29 20	44 67 7
Montreal	116	12 49 30 25	66 42 8
Toronto	87	15 27 11 34	36 41 10
Edmonton	37	11 13 11 2	8 29 0
Quebec City	31	9 15 5 2	8 17 6
Winnipeg	17	2 11 3 1	1 16 0
Calgary	15	0 11 2 2	3 11 1
Ottawa	13	2 5 3 3	6 2 5
London	8	1 5 1 1	5 2 1
Sum	*442*	*71 186 95 90*	*177 227 38*
Mean	*49*	*8 21 11 10*	*20 25 4*
Median	*31*	*9 13 5 2*	*8 17 5*

Notes: 1* Affiliated with SBFs.
2* Linked to SBFs.
3* Affiliated both with SBFs and Canadian universities.
Source: Thomson Bioscan (2002)

The same phenomenon holds true to patents awarded to biotechnology firms. First of all, and surprisingly, when compared to smaller cities such as Quebec, Vancouver, Calgary, and Edmonton, Toronto loses its dominant position when normalised for population size. The biotechnology firms in certain small Canadian CMAs seem surprisingly active in terms of patents.

Table 3 represents the total sample of bioscientists with affiliations with or links to biotechnology firms, shows that approximately the same proportion of bioscientists and biotechnology firms can be found in Vancouver, Montreal, and Toronto (73%). Considering population size and after normalisation, a large number of bioscientists (biotechnology superstars and biotechnology stars) are active in smaller metropolitan areas such as Quebec, Edmonton, Winnipeg and even London (see Table 4). Vancouver, however, remains in first position for the total number of bioscientists active in biotechnology firms.

The bioscientists are actively affiliated with or linked to 130 biotechnology firms. The median number of bioscientists per firm is three. Nearly 40% of these researchers are directly affiliated with senior management. In contrast, 52% are linked only by patents and scientific publications. Some bioscientists (38, meaning 8%) hold management positions in biotechnology firms while retaining their university professorships. The Montreal CMA has the highest concentration of affiliated bioscientists. Combining affiliations to biotechnology firms (profile 1*) and those to biotechnology firms and universities (profile 3*) gives Montreal 74 bioscientists out of a total of 116 researchers. Therefore, nearly 64% of the bioscientists active in this area are directly involved in the creation and development of biotechnology firms (see Table 4).

Table 4 Number of bioscientists and their association with SBFs by Canadian CMA in 2002 (normalised population*)

CMA	*CMA census population*	*# Scientists*	*Star scientist model*	*Bioscientist model*	*# by profile association*
			1A 1B 2A 2B	*1a 1b 2a 2b 2b*	*1* 2* 3**
Vancouver	1,986,965	*98*	4 7 31 56	12 37 25 24 3 21	*43* 50 5
Montreal	3,426,350	56	4 2 27 23	15 17 4 9 1 17	*34* 18 4
Toronto	4,682,897	31	4 3 10 14	17 21 22 5	15 13 3
Edmonton	937,845	65	0 0 17 48		19 46 0
Quebec City (majuscule)	682,757	75	12 0 33 30	23 33 12 7	24 37 14
Winnipeg	671,274	41	0 8 17 16	6 24 8 3	3 35 3
Calgary	951,395	26	0 2 12 12	0 17 4 5	6 18 2
Ottawa	1,063,664	20	0 0 8 12	3 7 3 7	11 3 6
London	432,451	30	0 10 5 15	3 17 5 5	22 7 1
Sum	*14,835,598*	*442*	*24 32 160 226*	*71 186 95 90*	*177 227 38*
Mean	*1,648,400*				
Median	*951,395*				

Notes: *Based on the latest census population

1* affiliated with SBFs.

2* linked to SBFs.

3* affiliated both with SBFs and Canadian universities.

Source: Statistics Canada (2002b) and Thomson Bioscan (2002)

When all CMAs are taken together, 79.5% of bioscientists are directly involved in the management of biotechnology firms in Montreal, Toronto, or Vancouver (Profile 1* and profile 3* = 171 out of a total of researchers with single and double affiliation). Moreover, the proportion changes when population size is taken into account, in which case the number of affiliated bioscientists is divided between Vancouver, Montreal, Quebec, London (Ont.), and Edmonton (Alberta), accounting for 77% and casting Toronto in the background.

3.3 Accounting for the influence of bioscientists on biotechnology-firm performance

Hypothesis H2 argues that the presence of bioscientists correlates positively to employment growth. The various types of researchers are included in the model in order to measure if they truly represent the performance factors for biotechnology firms, either because they facilitate knowledge transfer to the firm or because they enable the creation of new ideas leading to quality patents, venture capital, patent citations, and the publication of scientific articles. We also decided to include company age and venture capital in the model (as in Niosi, 2003).

Table 5 Correlation to SBF employment growth (R^2)

Bioscientist model	*E.97-02*	*Citations*	*AGE*	*V.C.*	*Bio-Sstars**	*Bio-Stars*	*Bio-Coll.A**	*Bio-Coll.B**
E.97-02	1.00							
Citations	.545*	1.00						
AGE	.340*	.401	1.00					
V.C.	.121	.120	.036	1.00				
Bio-Sstars	.419*	.104	.119	.245	1.00			
Bio-Stars	.637*	.340	.306	.303	.399	1.00		
Bio-Coll.A	.199	.150	–.011	.189	.263	.322	1.00	
Bio-Coll.B	.234*	.058	–.107	.163	.213	.189	.071	1.00

Notes: Bio-Sstars*: Bio-superstars
Bio-Coll.A*: Bio-collaborators type A
Bio-Coll.B*: Bio-collaborators type B
*Significant ($p < 0.05$)

The results revealed that most of the biotechnology firms that experienced job growth between 1997 and 2002 had relations with biotechnology stars (Table 5). Variables such as age of the firm, venture capital, and certain types of bioscientists were meaningful, but were eliminated during multiple linear regressions. As for genetic-sequence discoveries, the correlation with job growth (threshold: 0.919) and R^2 is very low, at 0.089.

Table 6 shows that the model confirms the role of scientists holding patents. Consequently, we found a relationship between the presence of star bioscientists (186 bioscientists with two to four patents), patent citations, and job growth. The presence of star bioscientists explains 43.4% of employment growth.

Table 6 Explaining employment growth

Model	R^2	*F*	*Sig. (one-tailed)*	*B*	*Std. E.*	*Beta*	*T.*	*Sig.*	*VIF*
Star bioscientists	.434	48.865	.000[a]						1.130
Constant				1.139	4.847		.675	.934	
Citations				1.337	.291	.238	3.915	.004	
Bio-stars				12.369	2.237	.539	3.713	.000	

Notes: Dependent variable: employment variation 1997–2002

a Predictors: constant, patent citations, bio-stars

Consequently, the number and quality of patents that researchers bring with them are what is most important to Canadian biotechnology firms. Innovation outputs, represented by patents and patent citations, are real factors in job growth.

These results also demonstrate that bioscientists play active roles in biotechnology-firm development: there is a direct relationship between the number of bioscientists in a company and job growth. This stands out as an important determinant of the relationships between knowledge capital and biotechnology-firm performance. Biotechnology firms with close ties to active bioscientists who have made important discoveries (whether they are founders, managers, or simply linked by co invention) leapfrog the start-up phase and achieve higher performance in terms of job growth than firms without such contacts. As a result, we can infer that these new institutional arrangements help drive the performance of biotechnology firms. Some 51% of the 442 bioscientists holding patents are linked to a technology firm through co inventions. This means that more than half of the studied population of researchers is composed of university-based bioscientists who are very active in the growth of biotechnology firms and who serve as economic agents in the development of these companies.

As demonstrated by Zucker et al. (1994, 1995), in some way, Canadian bioscientists who have made major biotechnology discoveries use agreements to establish collaboration with existing firms or create their own companies in order to profit from their inventions. Accordingly, nearly 40% of these researchers are directly affiliated with biotechnology firms. Moreover, those in a specific category (8.5%) wear two hats by heading up biotechnology firms while working as university professors. As we can see, nearly half of the bioscientists are involved in the management of these firms. Consequently, the different roles played by bioscientists and their research productivity can have a real impact on the performance of biotechnology firms.

Lastly, enhanced research productivity and job growth occur in firms with specific ties to the different types of high-caliber bioscientists. The results also show that biotechnology firms locate where bioscientists create their inventions. In this study, we have found that most of the bioscientists connected to biotechnology firms, either through patents or affiliation, are found in the same region. At this stage, our analysis of the ties between bioscientists and biotechnology companies confirms the hypothesis put forward by Zucker et al. (1994, 1995, 1998) regarding the importance of geographic proximity to the creation and performance of biotechnology firms.

4 Conclusions

A number of biotechnology firms experiencing strong growth take advantage of multiple cooperative endeavours with many high-calibre bioscientists. The main goal of these biotechnology firms is therefore to build a strong knowledge-capital base that is difficult to imitate but is mastered by high-calibre scientists. Knowledge represents a valuable creative asset and university researchers involved in the development of biotechnology firms, as holders of knowledge capital, become crucial economic actors. Consequently, the transfer of their knowledge capital to biotechnology firms represents a valuable strategic asset over long periods of time, providing, e.g., leverage in obtaining the financing needed to further innovation activities (product development can take 15 to 20 years). Concurrently with these fundamental dynamics, all of the actors involved are or can be linked to companies through contractual or property agreements, enabling them to appropriately respond to the imperatives of extremely competitive markets.

A previous study (Niosi, 2003) showed that, at the end of the 1990s, patents, venture capital, the targeting of export markets, and strategic alliances accounted for 80% of the growth of Canadian biotechnology firms. Our research brought to light two other major determinants: the influence of bioscientists and the importance of patent citations. Both are also indicators of the quality of patented discoveries and reveal the acquisition of exclusive know-how that gives a competitive advantage to biotechnology firms.

In summary, we have shed new light on the debate between spillover effects and knowledge markets by delimiting the profiles of researchers involved in biotechnology development. We observed commercial and non-commercial transactions in Canadian biotechnology firms because half of the bioscientists are either in management positions and/or owners of these firms. This study opens new avenues of research on the affiliation dynamics of university-based researchers. This phenomenon could be studied in other countries and comparisons could be made to determine if the same innovation determinants and structures are present. The importance of interdependence between institutions and private companies was identified in this research. University researchers play increasingly varied and active roles in innovation development and biotechnology commercialisation.

Our findings for the new biotechnology firms and clusters can be generalised to many knowledge-based sectors such as aerospace, medical and professional equipment, semiconductors, software, telecommunications equipment and services. Both organisational and technical innovations increasingly emerge from the interaction of several organisations with complementary knowledge assets. Like in the case of biotechnology, innovation and growth in these sectors depend more on the participation in a network of private and public companies, universities and government research centres than on a single isolated actor. The technological boundaries of the biotechnology firm, as in other science-based activities, are constantly expanding. Successful firms must adjust to the new context of innovation. Rapid growth depends on the absorption and use of new knowledge, and for such purpose, companies must relate to knowledge-producing institutions and usually cluster around them. Yet, biotechnology firms select some particular modes of knowledge production and absorption. These include the attraction of star scientists, patent production and knowledge licensing as well as collocation close to research universities.

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Notes

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