Are Firms at the Scientific Forefront also at the Technological Frontier?

Éric Archambault
Science-Metrix, Observatoire des sciences et des technologies (OST), Centre interuniversitaire de recherche sur la science et la technologie (CIRST), Université du Québec à Montréal, Montréal (Québec), Canada. Email: eric.archambault@science-metrix.com

Vincent Larivière
Observatoire des sciences et des technologies (OST), Centre interuniversitaire de recherche sur la science et la technologie (CIRST), Université du Québec à Montréal, Montréal (Québec), Canada. Email: lariviere.vincent@uqam.ca

Abstract

There is evidence in the literature that technological inventions comprise an increasing connection to scientific knowledge as exemplified by the increasing number of citations to scientific papers in the prior art sections of granted patents. If firms are indeed increasingly citing science in their research, two questions are raised: 1) Are firms conducting more scientific research? 2) Is being at the scientific forefront helping firms also to be at the technological frontier? This paper examines scientific output, as measured by numbers of papers, and technological output, as measured by patents of Canadian firms, during the 1980 to 2004 period. The study also looks at the scientific and technological output of firms that have published scientific papers and also hold US patents. We found that, although increasing, basic scientific research and patenting by Canadian firms is at near "homeopathic" levels. Our research also suggests that the number of firms publishing papers and obtaining patents is increasing over time and that, overall, these firms are at both the scientific forefront and the technological frontier. The theoretical framework of our study suggests that in publishing papers, firms trade short-term economic benefits in favour of establishing their reputations as leading firms, which is subsequently translated into a competitive technological advantage.

Introduction

According to Narin, Hamilton and Olivastro (1997), there is a growing link in the US between technology and public science. Technological inventions have strong connections with scientific knowledge as exemplified by the increasing number of citations to scientific papers in the prior art sections of granted patents. If the trend is for enterprises to increasingly cite science in their research, two questions are raised: 1) Are firms increasingly conducting scientific research? 2) Is being at the scientific forefront helping firms also to be at the technological frontier?

While there is an abundant literature on why firms apply for patents, there is a relatively scant literature on why they perform scientific research and why they publish their results. Although there is a wide consensus that firms want to obtain patents in order to obtain a monopoly position, which will be converted in economic benefit, this would also suggest that firms would be reluctant to publish their results because putting their knowledge into the public domain would deny them a monopoly over this knowledge, and result in a subsequent loss of economic competitiveness. The literature has proposed several reasons for this seeming anomaly. Whatever their precise reasons for conducting basic research, firms must be expecting an economic return of some sort, most likely from increased competitiveness. These important issues are examined in this paper through a systematic investigation of the published output and patents granted to Canadian firms between 1980 and 2004.

The first part of the paper reviews the literature on why firms perform basic scientific research and why they publish their results. The second part of the paper describes the methodology, the third presents the results of this study, and the fourth part is a discussion.

Why do firms perform basic research?

The link between science and technology (S&T) in private firms became institutionalised in the 19th century. For instance, around 1868, German firms in the aniline dye industry started to systematically hire university-trained chemists (Beer, 1958). Despite the long-standing debate[1], and the worthy contributions still being made today[2], on the precise interactions between S&T, it is undisputed that the modern industrial fabric would be entirely different if it were not for the employment by industry of university graduates who have engaged in a wide range of scientific activity, ranging from highly applied and goal-oriented research, to advanced and basic research. Despite this, there is a dearth of information and data on the interaction between published output by firms and their technological performance as assessed by patenting activities.

Although the reasons for performing applied research, and R&D more generally, have been explored at great length by economists and historians of S&T, there has been less attention given to why firms perform basic scientific research. As Rosenberg (1990) notes, there appear to be major disincentives to performing basic research. The first is the imperfect appropriability of science and the related fact that social returns are significantly higher than private returns (Nelson, 1959). For instance, the disclosure of research results by firms through peer-reviewed scientific publications certainly increases social returns, but at the expense of private returns from the specific knowledge that is being diffused. However, such a reductionist view does not explain why firms perform basic science and why they publish their results. To explain why firms find it profitable to conduct basic research activities requires a more synthetic view.

Rosenberg proposes several reasons as to why firms fund and perform basic research. The first is to gain first-mover advantage: despite imperfect appropriability, being the first to accomplish the learning curves creates barriers to entry for other firms. The application of basic research and securing of patent protection allows the downstream market position to be consolidated. The second reason is that it is generally large firms that engage in basic research, and they can feel confident that the findings will be put to good commercial use across a diverse range of products and commercial networks. Another factor that should be considered is the unexpected and unplanned aspect of firms' activities. There was certainly a degree of serendipity in the discoveries of Louis Pasteur, who opened the door to the modern science of bacteriology, and Karl Jansky's discovery of cosmic background radiation, which he made while working for the Bell Laboratories, trying to identify the cause of static in transatlantic radiotelephone services. One can assume that Bell Laboratories profited more by divulging this discovery than by keeping is secret. The authors of this paper think that it would be interesting to investigate how often publications by private firms follow serendipitous discoveries.

One of the most powerful reasons for conducting scientific research is that it allows entry to information networks. This serves two functions. Firstly, as von Hippel (1987) points out, in the case of collaboration between rivals, to obtain information from a network, it is necessary to be a contributor to the work of the network (see also Harhoff, Henkel and von Hippel, 2003). Secondly, firms need to perform basic research to be able to absorb the knowledge that resides on the not-so-freely-available 'information shelf'. For instance, "a firm is much less likely to benefit from university research unless it also performs some basic research" (Rosenberg, 1990: 171; see also Mowery, 1983, Furukawa and Goto, 2006).

Rosenberg also said that firms often perform basic research in order to give them a better understanding of how and where to conduct research of a more applied nature. In addition, conducting basic research allows them to monitor and evaluate research conducted elsewhere.

[1] See *Technology and Culture* (1965) vol. 6 no. 4 for the papers by De Solla Price and Multhauf and commentaries by Beer and Condit.
[2] See, e.g., Narin and Olivastro (1992); Meyer (2000).

Finally, and it should be noted that this may apply more specifically to the US given the weight of its military-industrial complex, Rosenberg suggests that firms perform basic research in order to increase their visibility and eligibility for military procurement contracts.

Why, then, would firms divulge the results of their research?

One interesting hypothesis as to why firms publish the results of their scientific research is that if they encounter a research bottleneck, they may be keen to signal to the wider research community that a scientific problem is currently unsolved[4]. Another hypothesis is that firms that are behind in the patent race publish papers in order to change the prior art in the hope of slowing down competitors (Bar, 2006).

Alternatively, as we hypothesised above, firms sometimes publish the results of their scientific research when in the course of it they make serendipitous discoveries. These discoveries may seem too big to be kept secret; the knowledge created would confer much smaller economic returns than the longer-term positive effects of adding to their reputation. The important aspect of this hypothesis is that firms will trade the short-term gains potentially associated with proprietary knowledge against the gains to be achieved from improving their reputation. Muller and Pénin's (2006) work supports this explanation. For Muller and Pénin, firms that openly disclose knowledge are motivated by concerns related to reputation. For these authors, the benefits of having the reputation of being an innovator are huge. These benefits could also exist for firms that besides being innovators, are also considered to be at the forefront of science, such as was the case of the Bell Laboratories before the AT&T system was dismantled and the laboratories became a shadow of their former selves. For Muller and Pénin, a good reputation may facilitate access to financing, grants and subsidies, and may help to win contracts. It may play an important role in increasing innovative capability by enabling firms to attract the best researchers and find excellent partners with whom to collaborate on R&D projects. An excellent reputation and being at the forefront of science may, as Rosenberg, and Muller and Pénin suggested, make them attractive to the best academic and industrial partners and, should we add, to government scientists.

Thus, firms that perform basic scientific research might do so partly for internal reasons, such as increasing their stock of knowledge, which will allow them to develop their own products, but might also do it to orient their more applied research, understand what their competitors are doing and give them the capability to absorb knowledge generated elsewhere. When they openly disclose knowledge, through scientific publication, they do so, in many instances, to improve reputation and, over a longer time frame, to gain economic and technological advantages. In this context, it is relevant to examine whether firms at the forefront of science are also at the technological frontier, since this would give credence to the idea that performing scientific research increases competitiveness through the mediation of complex processes, such as deriving benefits from an increase in reputation.

Methods

This paper uses data from the US Patent and Trademark Office (USPTO) database and from the CD-ROM version of Thomson Scientific's Science Citation Index (SCI). A dataset was created comprising all Canadian firms that had obtained at least one patent or published one paper over the 1980–2004 period. Canadian firms were identified by the presence of a Canadian address in a paper or in the assignee field of a patent. Company names were standardised, which was a somewhat challenging exercise, since this project drew on data from two entirely separate databases. This was nevertheless essential to examine the connection between scientific and technological activities.

[4] This hypothesis was formulated by our colleague Jean-Pierre Robitaille whilst reviewing this paper.

Several other indicators are used in this paper to measure the scientific and technological impact of research. A widely used measure of the scientific impact of research is the number of citations received in subsequent papers (Garfield, 1979), a proxy for which, and despite its well known limitations, is the Journal Impact Factor (Vinkler, 2004). To measure the scientific impact of the research conducted by Canadian firms, this paper uses a variant of the impact factor (IF) termed the average relative impact factor (ARIF). This indicator takes account of the fact that citation patterns are different in each field and subfield—e.g. there are more references per papers in biomedical research than in mathematics—by dividing each paper's IF by the average IF of the papers in its particular subfield[6] for the same publication year. The ARIF of a given entity was computed using the average RIF for each paper belonging to it. When the ARIF is above 1, it means that an entity (e.g. a country, a firm) scores better than the world average; when it is below 1, an entity publishes in journals that are not cited as often as the world average (logarithmic transformations are sometimes used in this paper, in which case the baseline becomes 0). In this paper, firms are considered to be in the forefront of science if their ARIF is above 1. This is a fair assumption because the ARIF' value is greatly dependent on the scientific research performed in universities, and the performance of basic research is the raison-d'être of universities. If firms have an aggregate ARIF above the world average, then clearly they are making important scientific contributions.

Similarly, counting citations to patents in the prior art sections of subsequent patents is a potent metrics of their technological significance (Albert et al. 1991; Hall, Jaffe and Trajtenberg, 2000; Jaffe and Trajtenberg, 2002). For each USPTO patent owned by a Canadian firm over the period under study, its citations from other USPTO patents were compiled to produce an indicator of the technological impact of research conducted in Canadian industry. Here, it is assumed that, aggregately, the more highly cited patents are, the closer they are to the technological frontier.

It should be noted that citations are proxy indicators for reputation: the higher the number of citations, the greater the firm's reputation. Similarly, publishing in journals that have a high impact factor increases an organisation's reputation since there is an associative link between the journal's reputation (and journals that are highly cited can be expected to have greater reputation) and that of its authors: publishing in reputable journals increases their reputation. This paper examines whether firms are at the forefront of science by looking at whether they have an ARIF above the world average and whether they are at the technological frontier by verifying whether their patents are frequently cited in other patents.

Another indicator that is used in this paper is the "research level" (see Narin, Pinski & Gee, 1976; Pinski & Narin, 1976), which distinguishes between four levels ranging from applied (level 1) to basic research (level 4). This journal-level score was determined by Narin's team at CHI Research. Here, for each paper by a Canadian firm, a score was calculated by matching the degree of appliedness of the journal in which the article was published.

As is the case with all datasets, the ones underpinning this paper have some limitations. The main one is that, while numbers of scientific publications written by industrial researchers in Canada are a good measure of scientific output, patents may underestimate the output of Canadian technological research since they do not necessarily measure the place where invention took place; they identify the location where the intellectual property is held (IP) (see Archambault, 2002, for a distinction between these two dimensions of patents). Another limitation of our dataset is the fact that patents owned by independent Canadian inventors are not considered as firms' patents although, in some cases, the inventor(s) are the firms' owners.

[6] Journals were assigned fields and subfields using the classification system developed by ipIQ (formerly CHI Research).

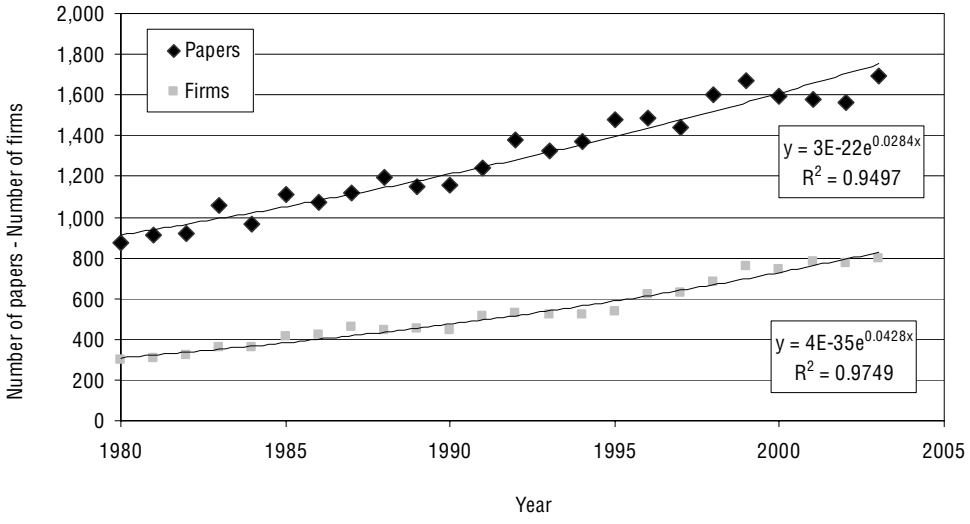
Results

This section describes scientific output measured by papers and technological output measured by patents for Canadian firms between 1980 and 2004 depending on data availability (2003 is the most recent year in some cases). All firms that published at least one paper indexed in SCI during this period and all firms that held at least one patent granted by the USPTO during the period are included in the sample. We examine the scientific and technological outputs of firms that published scientific papers and that hold US patents.

Canadian firms that publish

In the 1980–2003 period, 5,000 firms with a Canadian address published at least one peer-reviewed paper indexed in the SCI database. Interestingly, we found that the number of firms that published scientific papers increased at a 4.4% compound annual growth rate (CAGR), whereas the number of papers published by the same set of firms increased much more slowly at a CAGR of only 0.123%. There are two corollary consequences to these trends: there is a diversification of firms that publish papers; there is a diminishing average number of publications per firm. A detailed analysis of the data reveals that three institutions are largely responsible for the observed decrease in the average number of papers per firm. The publications output of Atomic Energy of Canada (AECL) and Hydro-Ontario, both of which traditionally publish on nuclear technology, radically decreased over the years. Also, the publications output of the Canadian subsidiary of Xerox also fell significantly. When these three organisations are removed from the dataset, the number of papers per institution becomes more stable.

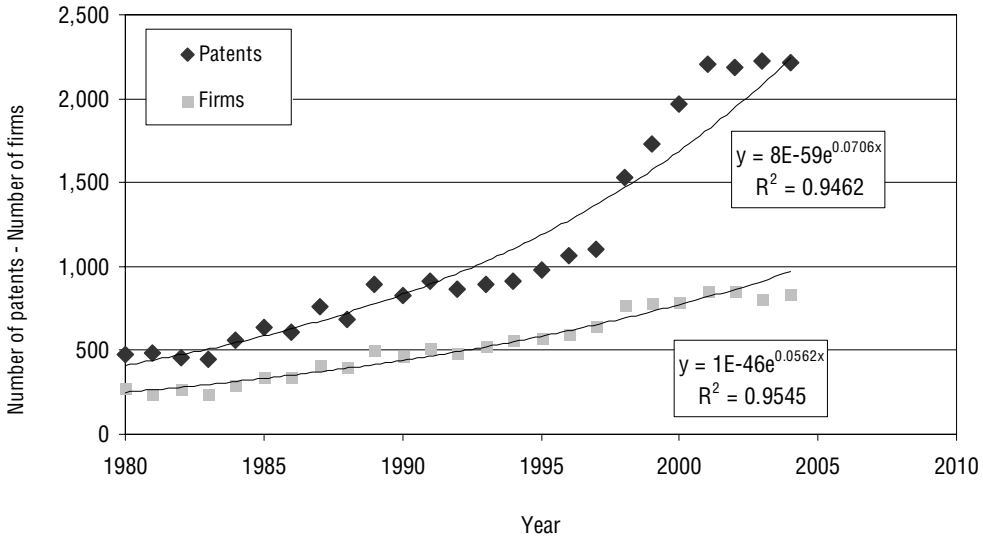
Figure 1 Number of papers and number of firms that publish, 1980–2003



Canadian firms that hold US patents

Figure 2 shows that the number of Canadian firms that were granted at least one US patent had a 6.0% CAGR, and that the number of patents grew even faster with a CAGR of 7.2%. The shape of the latter distribution is not purely exponential; it loosely follows an S-shaped curve. The number of patents granted to Canadian firms grew steadily between 1980 and 1997 and, similar to the trend for number of patents granted by the USPTO overall, peaked between 1998 and 2001 after which it reached a steady state. Figure 2 shows that the number of firms obtaining patents increased steadily across the whole period, while the number of patents per firm fell slightly between 1980 and 1997 but increased at a quite rapid rate thereafter.

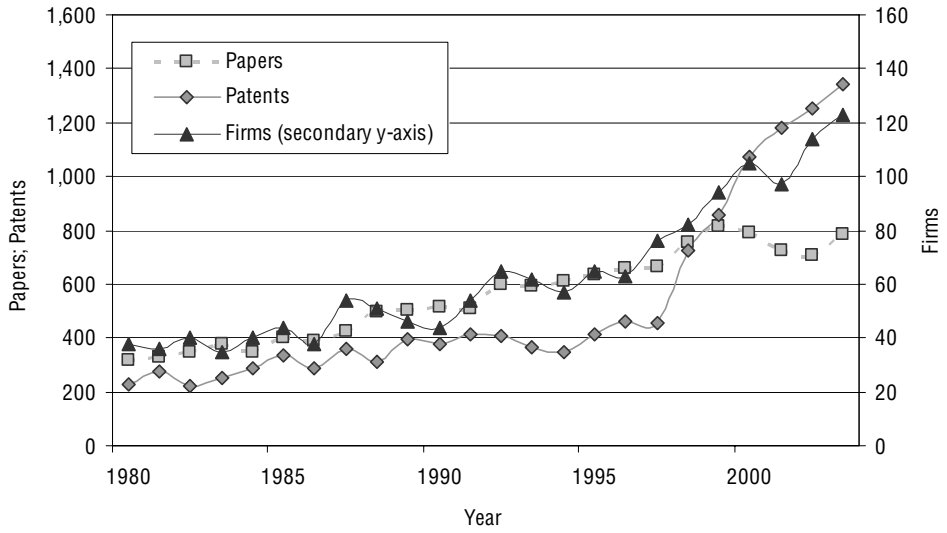
Figure 2 Number of patents and number of firms that hold patents, 1980–2004



Firms that hold patents *and* publish papers

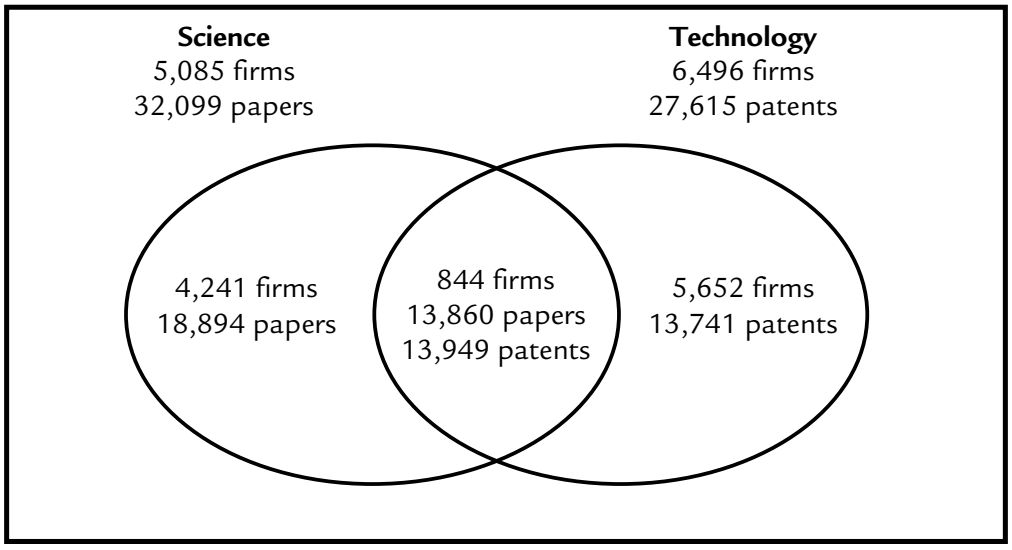
Combining the data on scientific publishing and on patenting produces interesting results. Firstly, there are about the same number of papers (approximately 32,000) as patents (approximately 28,000). This confirms the findings of other writers (see, e.g., Hicks, 1995), that publishing by firms is an important activity, and our data show that in the population of Canadian firms, publishing and patenting are almost equally frequent. Figure 3 shows that the number of firms that publish and also hold patents grew threefold between 1980 and 2004. It shows that up to 1999, the number of papers produced by these firms was greater than the number of patents obtained, after which time the number of patents granted clearly began to surpass the number of papers published. Over the whole period, the number of papers grew slightly more than twofold, while the number of patents granted to this group of firms increased about fivefold.

Figure 3 Numbers of papers and patents and number of firms that hold patents, 1980–2004



Our data reveal (Figure 4) that there is approximately the same proportion of firms that publish scientific papers but do not hold patents (83%) as firms that hold patents but do not publish (87%). Of the group of firms that published one paper or obtained one patent, only 7.4% both published and patented. Interestingly, firms active in both patenting and publishing had an average of 16.5 papers and 16.5 patents, which suggests that this population comprises a substantial number of large firms. By comparison, firms that only published produced only 4.5 papers on average, while firms that held patents but did not publish had 2.4 patents on average.

Figure 4 Venn diagram of scientific and technological output of Canadian firms, 1980–2004



The suggestion that firms that are active in scientific publications and patenting are large is supported by the fact that 43% of the published output is produced by firms that are committed to both types of activities, although these represent only 17% of the firms that published scientific papers during the period. Likewise, 51% of patents are obtained by firms active in both realms, and these represent a mere 13% of Canadian firms that hold a US patent granted during the period. When four outliers (Merck Frosst, Nortel Networks, Xerox and Alcan) are removed, the data show that there is a very weak correlation at the firm level between the number of papers published over the period and the number of patents held (r^2= 0.09).

Table 1 shows that in contrast to the importance given to the knowledge society discourse, Canadian firms on the whole have not entered or are far from having entered this paradigm. Overall, there were about 1 million Canadian firms in existence at any time during the last ten years. Only 1% of Canadian firms reportedly performed R&D in this period. Moreover, only some 0.1% of firms that were in existence in any one year published a paper or obtained a patent during that year. The percentage of firms that both published and obtained a patent during any year was 0.01% of the firms in existence. This shows that the concentration of firms publishing papers and obtaining patents is nearing "homeopathic" concentrations.

Despite these small numbers, Tables 1 and 2 respectively show that the number of firms with a scientific or technological output grew significantly over the period studied. More precisely, while in 1983 0.07% of the 752,700 Canadian companies had a bibliographic output (paper or patent), this share grew to 0.15% in 2003. For firms that were active in both realms, the concentration among firms reputed to perform R&D grew from 0.5% to 0.9%—a significant increase but a percentage that shows that this phenomenon is rare.

Table I Number of Canadian firms in the science and technology Landscape[7]

Year	Canadian Firms	Canadian Firms Active in R&D	Firms Publishing Papers	Firms Holding US Patents	Firms with both Papers and Patents
1994	918,000	11,132	520	560	57
1995	923,000	10,771	540	575	65
1996	925,200	9,805	619	595	63
1997	945,000	9,649	630	644	76
1998	957,900	9,784	682	771	82
1999	970,200	9,967	760	779	94
2000	980,800	10,849	745	788	105
2001	991,500	12,087	781	858	97
2002	1,003,000	12,272	777	854	114
2003	1,018,900	-	800	811	123

If we consider only Canadian firms that are reportedly active in R&D as the denominator, the relative importance of Canadian firms with one or both types of output is much higher and increased from 9% of firms in 1994 to 12% in 2002. The proportion of firms that reportedly performed R&D but only published grew slightly, from 5% in 1994 to 6% in 2002. Similarly, the proportion of firms performing R&D that obtained patents grew from 5% in 1994 to 7% in 2002. This shows that using only either papers or patents as indicators of activities for firms reportedly performing R&D is not commendable since, even in the best case (when both indicators are considered), for 88% of firms no output is measured.

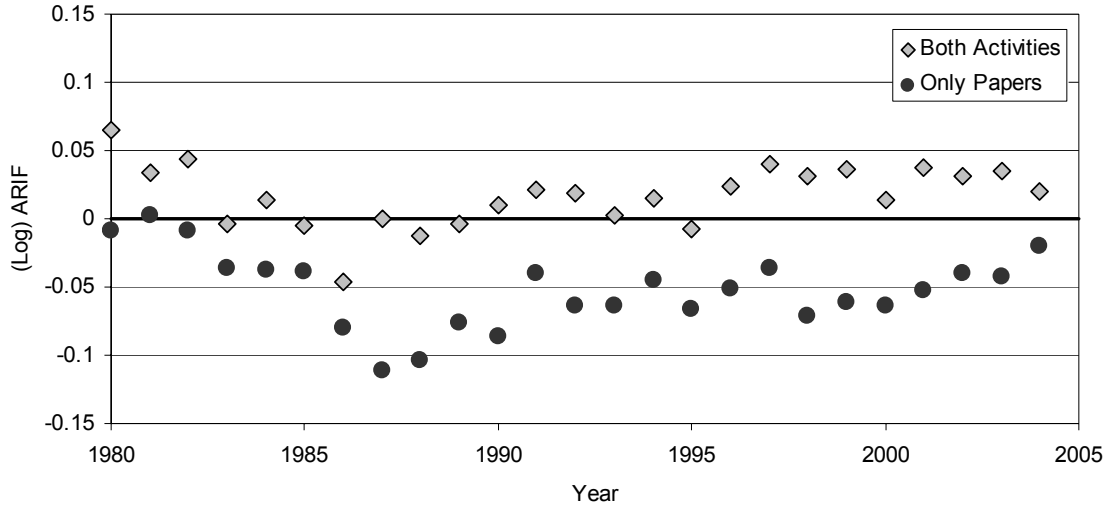
Are firms at the scientific forefront also at the technological frontier?

The previous section showed that only a small fraction of Canadian firms are active in both scientific and technological research. This section makes a qualitative examination of the specific characteristics of firms' output to answer the question as to whether firms that are at the scientific forefront are also at the technological frontier? In other words, are firms that pursue both types more likely to be at the forefront of science and at the technological frontier than those that only publish or only patent. Three indicators are used: ARIF, research level, and number of citations to patents in subsequent patents.

Figure 5 shows that firms that both publish papers and hold patents publish in journals that are more highly cited than firms that only publish papers (*t*-test on the aggregate yearly figures shows that $p<0{,}001$). This is interesting since it might have been expected that firms that only publish would produce higher quality output than firms that were also involved in the technological side. We cannot offer a micro-level explanation for this. It could be related to firm size or to specific sectoral patterns. Nevertheless, our data provide at least one hint that, at the macro level, firms active in both activities are more on the scientific forefront than those that only publish.

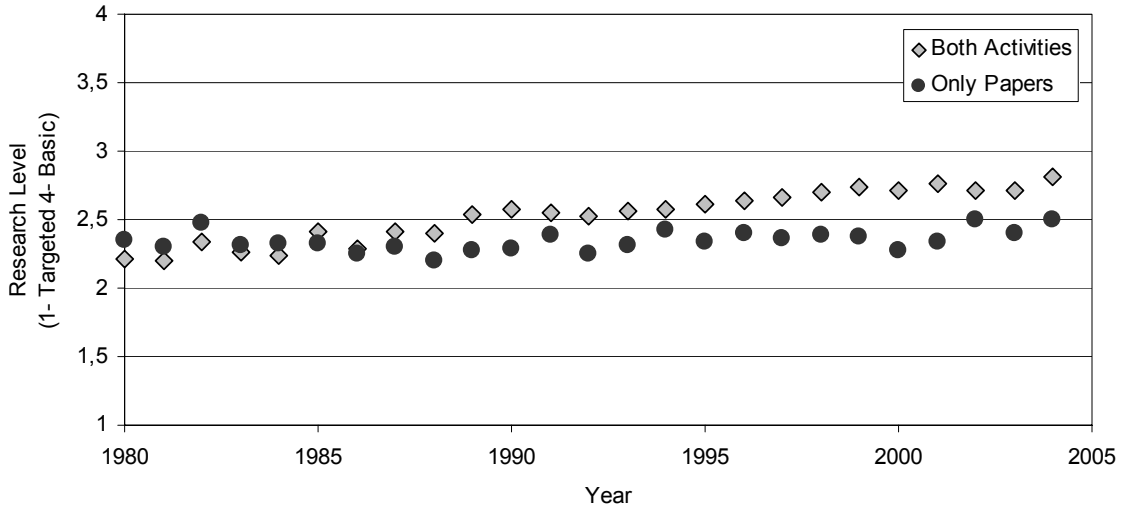
[7] Data on the number of Canadian firms active in R&D are from Schellings (2005); data on the global number of firms in Canada are from Kanagarajah (2006).

Figure 5 Average relative impact factor (ARIF) of Canadian Firms, 1980-2004



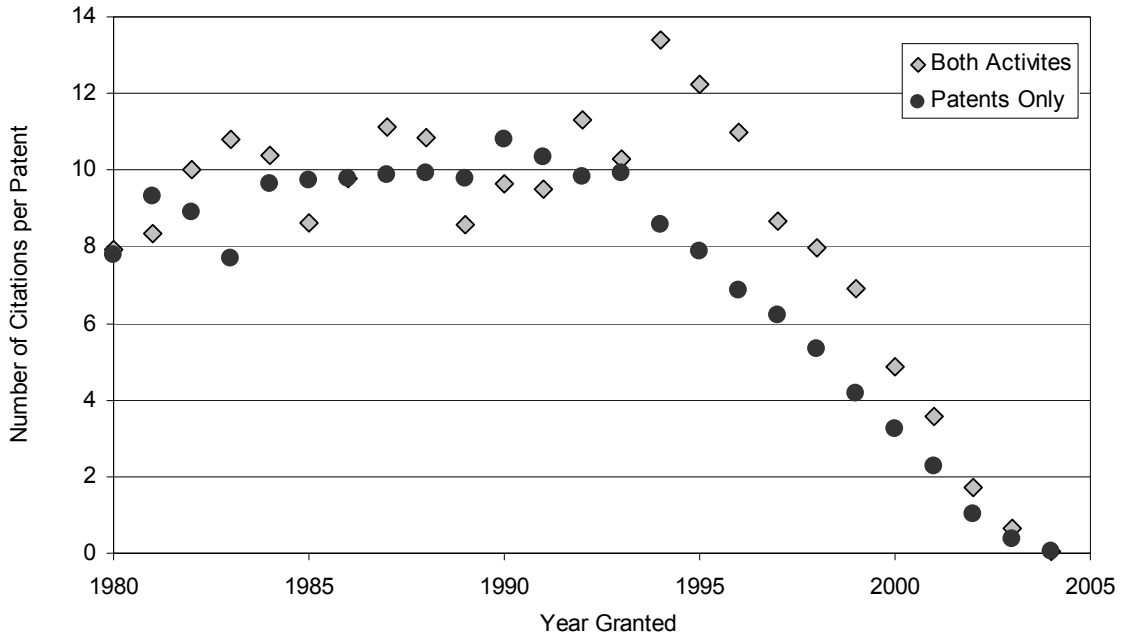
Similarly, using the research level of published output, Figure 6 shows that firms that publish papers and obtain patents have a tendency to perform more basic research (p<0,001) than those that only publish. Although this is not surprising in light of the previous finding (basic science journals are cited more on average than the more targeted research journals), it is not an intuitive result. It might have been expected that firms that only published would have performed more basic research than those that published and also had patents. However, it can be seen that Canadian firms involved in both scientific and technological research are nearer the scientific forefront than their counterparts that are active only in scientific research.

Figure 6 Research level of Canadian firms, 1980-2004



In terms of technological impact, Figure 7 shows that patents held by firms active in both patenting and publishing have a significantly higher impact (p<0,003) than patents owned by firms exclusively active in technology. This shows that technological research undertaken in firms active in both spheres of activities is more likely to be at the technological frontier than that of firms only active in technological research.

Figure 7 Number of Citations in Patents Received by Patents Held by Canadian Firms, 1980-2004



Conclusion

Our study has shown that the number of firms performing scientific research is increasing regularly. In Canada, the number of firms with a *measured* scientific output is growing at 4.4% per annum. This is somewhat slower than the growth in patents, where the number of firms obtaining a US patent is increasing at a rate of 6%. Therefore, our results confirm the increasing role played by science in corporate development.

Our research reveals that there are two types of bibliographic output among Canadian firms. Some firms have a more scientific profile, while others have a more technological fingerprint. It is important to note that there is little overlap between these two types of output and perhaps even more importantly, the vast majority of firms (99.85%), and even those reportedly performing R&D (88%), never publish a paper or obtain a patent. For the community of practitioners interested in the measurement of S&T, these results raise important questions since the commonly used output indicators are identifying only the tip of the iceberg. There are three aspects, likely not mutually exclusive, that need to be considered in further research on output indicators for enterprises: 1) the majority of firms that are reportedly performing R&D are not engaged in scientific or technological research, but rather are engaged in development work, which is not identified by indicators such as papers and patents; 2) firms reportedly performing R&D tend to be largely unsuccessful in this activity which means they produce little original knowledge that can either be published or patented; 3) the majority of firms performing R&D do not elect to publish or apply for patents as a result of their efforts.

This paper suggests that although there is no correlation between the numbers of papers published by firms and the numbers of patents they obtained, overall, firms that perform scientific research and that actively protect their inventions 1) publish in more highly cited journals than firms that only perform scientific research; 2) perform research that is more basic than firms that only publish scientific papers, but do not protect their IP with patents; 3) hold patents that are more frequently cited.

The theoretical framework suggest that, when publishing papers, firms trade short-term economic benefits in favour of establishing a reputation as a leader which is subsequently translated into a competitive technological advantage. Having a good reputation may facilitate access to various types of finance and may help to win contracts. A good reputation increases innovative capability by enabling firms to hire the best researchers and find excellent partners with whom to collaborate on R&D projects. The fact that firms that were active both scientifically and technologically published in highly cited journals give credence to the hypothesis that firms publish their scientific results to improve their reputation.

Bibliography

Albert, M.B., Avery, D., Narin, F. and McAllister, P. (1991). Direct Validation of Citation Counts as Indicators of Industrially Important Patents. *Research Policy* 20: 251-259.

Archambault, É. (2002) Methods for using Patents in Cross-country Comparisons. *Scientometrics* 54(1): 15-30.

Bar, T. (2006) Defensive Publications in an R&D Race. *Journal of Economics and Management Strategy* 15(1): 229-254.

Beer, J.J. (1958) Coal Tar Dye Manufacture and the Origins of the Modern Industrial Research Laboratory. *Isis* 48: 123-131

Beer, J.J. (1965) The Historical Relations of Science and Technology. *Technology and Culture* 6(4): 547-552.

Condit, C.W. (1965) Comment: Stages in the Relationships between Science and Technology. *Technology and Culture* 6(4): 587-590.

Furukawa, R. and Goto, A. (2006) The Role of Corporate Scientists in Innovation. *Research Policy* 35: 24-36.

Garfield, E. (1979) Is Citation Analysis a Legitimate Evaluation Tool? *Scientometrics* 1(4): 359-375.

Hall, B.H., Jaffe, A. and Trajtenberg, M. (2000). Market Value and Patent Citations: A First Look Economics Department, University of California, Berkeley, Working Paper E00-277. http://repositories.cdlib.org/iber/econ/E00-277

Harhoff, D., Henkel, J. and von Hippel, E. (2003) Profiting from Voluntary Information Spillovers: How Users Benefit by Freely Revealing their Innovation. *Research Policy* 32: 1753-1769.

Hicks, D. (1995) Published Papers, Tacit Competencies and Corporate Management of the Public/Private Character of Knowledge. *Industrial and Corporate Change* 4(2): 401-424.

von Hippel, E. (1987) Cooperation Between Rivals: Informal Know How Trading. *Research Policy*. 16: 291-302.

Jaffe, A.B. and Trajtenberg, M. (2002) Patents, Citations, and Innovations: A Window on the Knowledge Economy. Cambridge (USA): MIT Press, 478p.

Kanagarajah, S. (2006) Business Dynamics in Canada, 2003. Statistics Canada. Catalogue no. 61-534-XWE2006001.

Meyer, M (2000) Does Science Push Technology? Patent Citing Scientific Literature. *Research Policy* 29: 409-434.

Mowery, D.C. (1983) Economic Theory and Government Technology Policy. *Policy Sciences* 16: 29-43.

Muller, P. and Pénin, J. (2006) Why do Firms Disclose Knowledge and How Does it Matter? *Journal of Evolutionary Economics* 16(1–2): 85-108.

Multhauf, R.P. (1965) Sal Ammoniac: A Case History in Industrialization. *Technology and Culture* 6(4): 569-586.

Narin, F., Pinski, G. and Gee, H.H. (1976). Structure of the Biomedical Literature. *Journal of the American Society for Information Science* 27(1): 25-45.

Narin, F. and Olivastro, D. (1992) Status Report: Linkage between technology and science. *Research Policy* 21(3): 237-249.??not in text

Narin, F., Hamilton, K.S. and Olivestro, D. (1997) The Increasing Linkage between U.S. Technology and Public Science. Research Policy. 26(3): 317-330.

Nelson, R.R. (1959) The Simple Economics of Basic Scientific Research. *Journal of Political Economy* 67: 297–306.

Pinski, G. and Narin, F. (1976) Citation Influence for Journal Aggregates of Acientific Publications: Theory, with application to the literature of physics. *Information Processing and Management* 12(5): 297-312

Rosenberg, N. (1990) Why Do Firms Do Basic Research (with their own money)? *Research Policy* 19(2): 165-174.

Schellings, R. (2005) Industrial R&D Statistics by Region 1994 to 2003, Statistics Canada. Catalogue no. 88F0006XIE — No. 017.

de Solla Price, D. (1965) Is Technology Historically Independent of Science? A Study in Statistical Historiography. *Technology and Culture* 6(4): 553-568.

Vinkler, P. (2004) Characterization of the Impact of Sets of Scientific Papers: The Garfield (Impact) Factor. *Journal of the American Society for Information Science and Technology* 55(5):431–435.