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EVALUATION OF THE PRIVATE FUNDING OF UNIVERSITY RESEARCHERS AND ITS EFFECTS ON SUBSEQUENT PATENTING; CAN THE BIOTECHNOLOGY INNOVATION MODEL BE TRANSFERRED TO ENABLE EFFICIENT DEVELOPMENT IN THE FIELD OF NANOTECHNOLOGY?

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Abstract

Innovation in biotechnology greatly benefits from collaboration and networking between scientists and also institutions. Collaboration, whether it be financial or intellectual, between industry and university is particularly useful because the gap between science and technology is minimal in this area of research. Many sources suggest that the model of knowledge production in nanotechnology is similar to that of biotechnology and many projects are done, taking this into consideration. To the best of our knowledge however, no quantitative analysis has led to validate this in Quebec. We use funding data from the SIRU database and patenting data extracted from the USPTO database to map and compare the process of funding and of the subsequent patenting involving academic-inventors and organizations as both patent owners and funders. We find that the instances in which awarded funds actually lead to a patented invention are quite limited and that they are restricted to certain areas of nanotechnology. Furthermore, we find that the only case in which nanotechnology follows biotechnology is in the subfield of nanobiotechnology.

Keywords: Biotechnology, Nanotechnology, Collaboration, Innovation

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INTRODUCTION

In Quebec, as in Silicon Valley, there has recently been an increase in the relative importance of biotechnology for local economic development. This is even truer for nanotechnology, which is considered by many as being a key technology of the 21st century (Meyer & Persson, 1998; Roco, 2002; Hullman, 2006).

It is widely recognized that innovation in biotechnology and nanotechnology is heavily dependent not only on the funds injected into R&D efforts but also on the quantity and quality of collaboration between the various actors involved. This is due to the fact that the knowledge necessary to make important technological advancements is mostly tacit (Morone & Taylor, 2004). In addition, it is also recognized that because of the very fine line between applied and basic research in these fields, organizations wishing to innovate efficiently must associate with university researchers in order to do so (Robinson *et al*., 2007). Furthermore, many sources indicate that nanotechnology, because of its nature and the fact that it shares many similarities with biotechnology, follows a very similar innovation process (Darby & Zucker, 2003). However, to the best of our knowledge, no quantitative analysis demonstrating this has been performed in Quebec.

Hence, our study focuses on the best practices of innovation development in high technology in Quebec. More specifically we aim to map part of the innovation process that covers the actual funding of university researchers and the subsequent patenting that ensues. To what extent does the funding of a university researcher lead to patenting? Does the nanotechnology funding-patenting innovation process differ from that of biotechnology? In order to answer these questions, we map what we refer to as innovation loops, i.e. the instance in which a university researcher has received funding from an organization and has gone on to be listed as an inventor on a patent which is owned by that same funding organization. We also study 'loop-originated' patent quality and degree of application to examine similarity between the fields in question.

The first part of this paper contains a literature review in which we describe the nanotechnology and biotechnology industries in addition to the status of research, funding and innovation in both fields. The second part contains our data, hypotheses and methodology. The third part includes our findings and their interpretation. Finally the fourth part concludes, discusses the policy implications form our work and proposes directions for further research.

STATE-OF-THE-ART

In this section we aim to establish an understanding of current mechanisms enabling innovation in the high tech industries that are nanotechnology and biotechnology. In order to best understand the topic at hand we begin by reviewing the actual definition and scope of each field. We then proceed to examine the importance of collaboration from a funder's and fundee's point of view since this concept is at the heart of our innovation loops. We continue by evaluating some of the underlying similarities and differences between both industries to help shape our hypotheses.

Nanotechnology

What is nanotechnology? A wide array of definitions for nanotechnology exists and some are more inclusive than others. The OECD (2009) lists five acceptable definitions provided by various sources, i.e. the National Nanotechnology Institute, The Seventh Framework Programme of the Europeen Union, ISO TC229, Second Science and Technology Basic Plan, and New Dimensions for Manufacturing: A UK Strategy for Nanotechnology. On the one hand, this lack of a common definition makes the task of analysing this sector more complex than it would otherwise be and is at the source of differences in the predictions of the importance of nanotechnology and of its economic contribution. In fact, depending on the adopted definitions, scientometric and econometric inferences can greatly differ. On the other hand, it is important to mention that these definitions somewhat overlap and that generally speaking the definition given by Franks (1987)[1] is relatively well accepted by the scientific community (Meyer & Persson, 1998).

Putting semantics aside, we can now examine the importance of nanotechnology on a global scale. After gathering information from various sources, Hullman (2006) states that a significant increase in the nanotechnology product market is expected after 2010 and that it will make up almost 15% of all global manufacturing. Roco (2002) has estimated that worldwide industrial production in the nanotechnology field will hit 1 trillion USD within a 10 to 15 year horizon. All depending on the definition of nanotechnology and its contribution to the added value of final products, predictions of the global nanotechnology market vary between 150 billion USD in 2010 (Mistubishi Institute, 2002) and 2.6 trillion USD in 2014 (Lux Research, 2004) (Hullman, 2006). Furthermore, the NSF estimates that 2 million workers will be needed by the year 2015 (Roco, 2001). One of the main reasons the predictions of the nanotechnology market shares are so high is that it is recognized as being a key technology of the XXI century that will be as revolutionary and vital to areas like information technology as it will be for medicine (Meyer & Persson, 1998). For example, nanoelectronics are helping to continue Moore's law on doubling memory capacity and processing speed every 18 months (Hullman, 2006) and nanomaterials are used to administer certain medications.

On a global scale, the largest investors in nanotechnology R&D are Western Europe, Japan, the United-States and others (Australia, Canada, China, Eastern Europe, FSU, Korea, Singapore, Taiwan, and others) (Roco, 2002). Roco (2001) has identified many

[1] Franks (1987) describes nanotechnology as a technology where dimensions and tolerances ranging from 0.1 to 100nm play a critical role.

strategy trends for investment in nanotechnology R&D: (1) Different R&D hubs according to the country; (2) Training of personnel is a key to long term success; (3) Certain common technical and scientific obstacles cover large human goals; (4) A focus for manufacturing at the nanoscale; (5) Partnerships to encourage interdisciplinary and activity integration; (6) International collaboration. Even though many countries have injected large funds in the development of nanotechnology in the 80's and 90's, Roco (2001) states that nanotechnology has only evolved from science fiction to something concrete after President Bill Clinton announced the first coherent national nanotechnology program in January 2000 with the participation of key federal agencies of the academic and private sectors. This then led to the birth of national nanotechnology programs in practically all other developed countries in 2001, with the National Institute for Nanotechnology (NINT) in Canada. Hullman (2007) highlights the fact that, according to the European Commission, 37 900 000€ in public financing have been spent on nanotechnology R&D in Canada in 2005, which puts it in 16th place for the total amount of 3,85 billion euros. Therefore, almost 1% of worldwide public financing in nanotechnology R&D is spent in Canada. In terms of scientific production, Canada ranks 13th for the number of publications as of 2005 with 1579 publications (Kostoff *et al*., 2007). It is also important to mention that apart from having the NINT, Canada also has several provincial frameworks to support nanotechnology R&D: British Columbia Nanotechnology Alliance (Nanotech BC), NanoAlberta, NanoQuebec and the Nanotechnology Network of Ontario (OCDE, 2009).

Biotechnology

The OECD defines Biotechnology as the "The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services" (OECD, 2010). Given its broad definition, it is obviously somewhat older than nanotechnology, and some would even argue that it takes its roots in common agricultural processes like breeding programs, which have been around for thousands of years. Biotechnology has greatly evolved since its humble beginnings and now encompasses a wide range of applications, such as: computational biology also known as bioinformatics, marine applications, medical processes and industrial applications in chemical production for example. Modern biotechnology, or just biotechnology as we will refer to for the rest of this article, was born with the advent of recombinant DNA in 1973 and is the fruit of collaboration between two Californians, Stanley Cohen and Herbert Boyer (Darby & Zucker, 2003).

Key discoveries and breakthroughs have been incessant since the late 1970's and early 1980's and this is not only due to the hard work of the scientists involved but also due to the important private and public funding of biotechnology in both university and industry environments. In fact, total biotechnology R&D expenditures in the Canadian business sector were close to 944.5 million USD in 2008 (OECD, 2011)[2]. Moreover, according to the OECD (2011), public biotech R&D represents 6.69% of total public R&D expenditures. Furthermore, Canada is listed as one of the top countries as far as the revealed technological advantage in biotechnology indicator is concerned[3]. In terms of applications, as of 2006, 87.3% of R&D investments have been in the healthcare field, 9.2% in agriculture and the remaining 3.5% is spread out across natural resources, environment, industrial processing, bioinformatics and others (OECD, 2011).

University Researcher Funding and Innovation

University scientists receive funds as grants or contracts from various organizations and for many reasons. Many organizations fund academics as they have a vested interest in the researchers' success. Without appropriate funding most academics would not be as successful in their respective fields as they would otherwise be with funding. This is especially true in the cases of biotechnology and nanotechnology where the required support structure and equipment are not inexpensive (Robinson *et al*., 2007). Furthermore, increased publications by researchers reflect greatly upon the university to which they are affiliated. However, grant awarding bodies are not the only ones willing to award academics the necessary funds to conduct their research. Firms, foundations, associations, societies, health institutions and provincial corporations are examples of those also keen on providing funds.

In particular, Bonaccorsi & Piccaluga (1994) state that firms have many reasons to perform collaborative R&D with academic laboratories and that due to the growing gap between research costs and government funding, universities have sought resources from private firms in order to fund their research. They argue however that the motivations to start relations with universities are much deeper. For instance, firms require the building and improvement of their scientific knowledge base in order to recognize and exploit various technological opportunities. Also, it has been mentioned that certain non-trivial scientific milestones have been reached from solving common technical problems faced by companies in their various design and production activities. Furthermore, it has been suggested that external links with universities aren't replacements for funding of internal basic research because the firm's absorptive capacity is likely to be dependent upon previous investments in R&D (Bonaccorsi & Piccaluga, 1994). Generally speaking however, George *et al*. (2002) find that firms with university linkages have lower R&D costs and have higher levels of innovative output. Concerning the collaboration of firms and universities, Meyer (2006) points out that (1) growth in the specialisation of

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[2] According to the OECD's Directorate for Science Technology and Industry (DSTI).

[3] The revealed technological advantage indicator is calculated as the share of biotechnology in country's patents relative to share of biotechnology in total patents from http://www.oecd.org/document/30/0,3746,en_2649_34537_40146462_1_1_1_1,00.html

knowledge is pushing firms to increase their dependence on a combination of internal and external R&D (Brusoni *et al*., 2001; Grandstrand *et al*., 1997; Langlois, 1992) and (2) that there is a type of loose coupling in the sense that firms upkeep friendships with independent external sources, e.g. suppliers, universities, etc. that enable them to detect technological changes in sectors not limited to their own. One more reason brought up by Pavitt (1990) for keeping relationships with the universities is that important applications are often the result of research undertaken purely out of curiosity and that this type of research activity is most likely to be outsourced to universities (Bonaccorsi & Piccaluga, 1994).

Moreover private funding of university researchers is particularly important in nanotechnology and biotechnology; Narin *et al*. (1997) show that the intra-country connection between basic science (often conducted in universities) and applied science (often conducted in industry) is especially significant in areas of high technology, making university-industry links in these fields very valuable (Meyer & Persson, 1998). Furthermore, considerable research by Zucker *et al*. (1998) and Murray (2004) has shown that the performance of companies in the biotechnology field has been improved by the existence of links with academic scientists (Casper, 2007). As far as nanotechnologies are concerned, they are to an extent more multi-disciplinary and require expensive equipment and resources that actors involved may benefit from sharing (Robinson *et al*., 2007).

Scientists accept funds from firms for many reasons. Firstly, Gulbrandsen & Smeby (2002) come to the conclusion that contrary to popular belief, university-industry relations do not hinder academic objectives and rewards. Furthermore Gulbrandsen & Smeby (2005) find that scholars who benefit from external industrial funding publish more articles than their peers, confirming results presented by Godin (1998) and Geuna & Nesta (2006), even though they generally conduct less basic research than their peers (Meyer, 2006). It is important to note however that scientists are more prone to start working with firms after noticing that other scientists have greater citation and publications rates in doing so (Darby & Zucker, 2003).

Seeing how the subject of university researcher funding is becoming increasingly significant, we would like to examine if it is truly enabling efficient innovation and success for all parties involved. This brings us to our first question: to what extent does the funding of a university researcher actually lead to patenting?

Basis for nanotechnology and biotechnology comparison

It has been stated by Darby and Zucker (2003) that because the scientific discoveries underlying nanotechnology and biotechnology are essentially methods of inventing, that is to say, that they create technological opportunity and appropriability across many disciplines, they expect to observe a similar development. In many respects, the nanotechnology boom has been considered similar to the biotechnology boom

(Rothaermel & Thursby, 2007). Darby and Zucker had performed analyses of nanotechnology patenting, publishing and entry of start-ups in proximity to universities that have shown similar patterns to analyses performed in the field of biotechnology (Darby & Zucker, 2003; Zucker *et al*., 1998; Rothaermel & Thursby, 2007). One might then argue that if all these elements are similar, then researcher funding and subsequent patenting should also be so.

In this article, we use patenting data as it is a major indicator of innovation[4]. Darby & Zucker (2003) indeed mention that patents are very important in the protection of biotechnology products. Patents mostly come into play somewhat after their invention however, as natural excludability[5] initially provides informal protection by slowing the diffusion of knowledge (Zucker and Darby, 1996; Zucker, Darby and Brewer, 1998; Darby & Zucker, 2003) in both biotechnology and nanotechnology. Darby & Zucker (2003) state that given a similar state of maturity, and taking into account the time lag, the scientific and patenting growth of nanotechnology follow that of biotechnology. Furthermore, using patents as a measure of inventive output, Rothaermel & Thursby (2007) illustrate the nanotechnology and biotechnology time series and show that if the nanotech series were lagged by 4 years, it would would yield a correlation coefficient of r=0.95 with the biotech series. This last statement provides some basis for the hypothesis that biotech and nanotech development follow similar patterns, at least as far as patenting is concerned.

This brings us to the second main question we would like to answer: does the nanotechnology funding-patenting innovation process differ from that of biotechnology?

DATA, HYPOTHESIS & METHODOLOGY

Data

We use funding data extracted from the *Système d'Information sur la Recherche Universitaire* (SIRU), which is a system that compiles government, industry and university grants and contracts awarded to university professors and researchers in Quebec. SIRU is run by the *Quebec Ministry of Education, Leisure and Sports* and provides insightful information concerning financial collaboration between university researchers and organizations. All grants and contracts that transit via the university accounts to fund academic research are accounted by this system. For the purpose of this analysis we use data that span from 1983 to 2005. Any data included in the time period

[4] We use patenting as a measure of innovation output for a couple of reasons. First of all, as Rothaermel & Thursby (2007) remind us, patents represent novel, non-trivial and useful inventions. Second, patents contain information pertaining to both inventors, i.e. scientists, and assignees, i.e. firms, and are essentially the only open way of linking these actors to one another.

[5] This comes from the fact that before codification, leading discoveries often involve extensive tacit knowledge that is embodied initially only in the discoverers and passed on by learning by doing (Darby & Zucker, 2003).

after 2005 would not be useful since a 22 year interval is more than enough to find tendencies and map the funding evolution. The SIRU table (see annex A) contains each instance of funding to a Quebec University researcher in the fields of nanotechnology and biotechnology per year. For each instance of funding we have the following information: (1) the year of funding; (2) the first and last name of the scientist receiving funding; (3) the title of the project on which the scientist is working; (4) the institution to which the scientist is affiliated; (5) the name of the department to which the scientist is affiliated; (6) the name of the funding organization; (7) the category of the funding organization; (8) the origin of the funding organization; (9) the type of funding that was awarded, e.g. grant or contract.

The patenting information was extracted from the *United States Patent & Trademark Organization* (USPTO) database using a keyword search (Barirani et al., 2011) compiled with information retrieved from Mogoutov & Kahane (2007), Porter et al. (2008), Schmoch et al. (2003), Alencar et al. (2007), Zitt & Bassecoulard (2006) & OECD (2009) to identify the appropriate nanotechnology and biotechnology patents. The *Canadian Intellectual Property Office* (CIPO) would have been an interesting additional source of patent data. However the CIPO database does not contain as much information as the USPTO (e.g. the addresses of inventors are missing) rendering inventor and organization matching more difficult and less accurate. Furthermore, as Schiffauerova & Beaudry (2009) point out, the USPTO is for many reasons a more than acceptable source. The patent data span from 1976-2009 and for each instance we have the following variables: (1) the patent identification number; (2) the patent title; (3) the patent abstract; (4) the year of application; (5) the year of patent granting; (6) the number of claims associated to a patent; (7) the names of the patent assignees; (8) the name(s) of the inventor(s); (9) the type of patent; (10) the number of citations each patent has received.

Hypotheses

The similarities between biotechnology and nanotechnology highlighted earlier in this paper are not few, to say the least. However, there is also evidence that they are not as alike as it may seem. Rothaermel & Thursby (2007) find that patenting in biotechnology is explained by knowledge gained outside the firm, especially from R&D alliances, as well as its previous knowledge base. Dividing a 20-year period from 1980 to 2000 into two, 1980-1990 and then 1990-2000, they find that biotechnology was more prone to external R&D alliances in the first part and then more focused on internal R&D expenditures in the second, as opposed to nanotech in which R&D expenditures are significant in both periods[6]. This suggests that biotechnology firms relied on alliances

[6] This is explained by the fact that the time before the instrumentation for the first enabling technology for biotechnology, i.e. automatic gene sequencing, was available for almost 20 years (Zucker *et al*., 1998) and nanotechnology's enabling technology, i.e. the scanning tunnelling microscope (STM), was developed in 1981 and the employed instrumentation, the Atomic Force Microscope, was commercialised in 1989

and acquisitions much longer than incumbent firms in nanotechnology. This leads us to propose the following hypothesis:

Hypothesis 1: Even though they present many similarities, nanotechnology and biotechnology do not follow the same innovation development pattern.

Our analysis is relatively exploratory. However, it wouldn't be farfetched to believe that because biotechnology and nanobiotechnology are similar in nature, they follow a similar innovation pattern. We might have limited data on this as Hullman (2007) points out that even though Canada's nanotechnology development is more and more dynamic, the country has a tendency to specialize in nanomaterials and nanodevices. Be that as it may, we propose the following hypothesis:

Hypothesis 2: Nanobiotechnology follows a similar pattern of the innovation creation process as biotechnology.

Furthermore we can suppose that since patents that are part of loops and assigned to firms are born of collaboration, they should present higher quality than patents that are out of loops. This quality can be measured in several ways; however we choose to use the number of claims associated to a patent as a first measure of quality and the number of citations as a second measure of quality. Claims are a good indicator of quality since they relate to the scope of a patent: the higher the number of claims, the larger the scope, the better the quality. As far as the citation rate goes, it is apparent that the more a patent is cited, the more importance it has in enabling further innovation, thus the higher its quality. In any case, these measures have proven useful to measure quality in the past and have been successfully used by many (Trajtenberg, 1990; Lanjouw & Schankerman, 2004; Bonaccorsi & Thoma, 2007).

Hypothesis 3: Both nanotechnology and biotechnology patents that have been generated by innovation loops are of higher quality than those produced out of loops, i.e. (a) they have more claims and (b) they have a higher citation rate.

Seeing as how there is a gap between researcher financing and subsequent patenting, we would like to test whether or not the extent of the gap implies a difference in the degree of application of the knowledge associated with it. This is somewhat of an empirical hypothesis that we nevertheless feel would be interesting to test and compare for both nanotechnology and biotechnology. Furthermore, we can contribute to the similarity analysis between biotechnology and nanotechnology by analysing the difference in the degree of application between both. Essentially, because their applications cover different fields, some less applied than others, journals publishing articles covering inventions in one should be of a different degree of application than the other.

(Darby & Zucker, 2003). Therefore, Rothaermel & Thursby (2007) state that incumbent firms in biotechnology should rely on alliances, mergers and acquisitions a lot longer than firms in nanotechnology.

Hypothesis 4: (a) Inventions with a larger time lag between the funding and the patent filing are of a more applied nature than those with a smaller time gap. (b) The knowledge associated with nanotechnology patents is of a more applied nature than the knowledge associated with biotechnology patents.

Methodology

Scientist name identification & matching

How do we match a scientist that has worked on an invention and that has his name listed as an inventor or co-inventor of a patent with himself in the SIRU funding database? We start off by examining the available information in each set of data. An inventor has 4 pieces of information listed on a patent: his first name, his last name, his location, i.e. his town and country and in some cases his state or province, at the time of the patent application, and the assignee's name. The funding data is considerably more complete, as it contains the scientist's first and last names, serial number, the project on which he is working, the institution to which he is affiliated and its location. Therefore our ability to potentially match a scientist from our patent database to our funding database is somewhat limited. There are two issues concerning the scientist matching process (1) homonymy and (2) synonymy. Calero *et al*. (2006) were confronted to a similar problem when trying to identify research groups using publication analysis in the field of nanotechnology. To reduce the homonymy problem, in other words the probability of two or more researchers having the same name, they create an author/organization combination. However, in our case, this does not help because our data span across nearly 3 decades, and most researchers have had time to move around and work at various universities and firms and this would create a lot of noise in our analysis. To decrease the impact of the synonymy problem, Calero *et al*. limit their data to a single country and only keep combinations with 6 publications or more. Our synonymy problem is limited by two factors: (1) our data is limited to Canada for patents and to Quebec for funding, (2) in the data preparation, a thorough analysis has been done to correctly match scientist names from Elsevier's SCOPUS, the Canadian granting councils[7] databases and the USPTO database. In fact, all names listed were examined one by one and each researcher or scientist was assigned a serial number based on a specific procedure. This ensured that, no matter the orthography, a given person who has spelled his name differently when publishing an article, applying for a grant or inventing a product or process would be identified as the same person. When applying this strategy to the SIRU

[7] Elsevier's SCOPUS is a database that contains citation and abstract information on over 18 000 scientific journals. The Canadian granting councils database contains information on Governmental funding of Canadian researchers by the Natural Sciences and Engineering Research Council, the Canadian Institutes of Health Research and the Social Sciences and Humanities Research Council. Even though these databases are not directly required for the purpose of our analysis, using them increases the accuracy of our matching process (as we cover more scientist synonym names) and they will be useful in further analyses.

database, we cover a large number of scientist synonym names, thus decreasing our chances of omitting potential name matches.

Assignee identification & matching

Each patent has one or more assignees that have ownership over the right to manufacture and distribute their invention. In our case, one of the main challenges was to be able to match the names of the funding companies or institutions with the names of the nanotechnology and biotechnology patent assignees. At first glance, this procedure would seem trivial but this is hardly the case. Even though we did not encounter homonym problems much, as with the scientist name matching, the synonym aspect is quite a problem. To ensure that each organization was given the proper assignee identification number, we went through each of the 49,172 records from our patent-assignees table and manually attributed the proper identification number to each assignee. This exercise took into account corporate restructurings, name variations (including French to English) and known horizontal mergers, although it is important to mention that most of the corporate history related to private SME's was somewhat limited. Having properly identified each assignee, we matched the assignee names with those listed in the funding organization name column of the SIRU database using a SQL pattern search. This methodology yielded 7,465 collaboration results. To improve our pool of matched data we added 226 alternate identifying names to our list of names to match (link_assignees_siru). We also ignored all stopwords and superfluous text (i.e. corporation, incorporated, limited, etc.) while ensuring that common assignee names would not be mistakenly associated. For example, Whitaker corporation is not the same entity as Whitaker foundation, hence by removing corporation from the search pattern we would have mistakenly identified the Whitaker foundation as being an institution that has both provided funds for bio research and been granted a patent in that field. Taking this into account, our detailed search pattern yields 10,891 potential collaboration matches with a total of 360 different funding institutions and 1,539 individual researchers spanning 23 years, form 1983 to 2005.

Looping

Having properly identified and matched (1) the academic-inventors from the SIRU database of scientists receiving funding, (2) the funding providers-assignees from the SIRU database and (3) the academic-inventors with the funding providers-assignees from the patent database, we can easily identify the complete innovation loops. Once the initial task of creating our innovation loops was accomplished, we concentrated on reviewing the content of each loop to ensure that they actually represented instances in which awarded funds had led to patenting. We decided to examine the content of each loop manually, keeping all potential loops including those that may have a time lag as large as 25 years between funding and patent filing. We do so for two reasons: (1) only a thorough qualitative analysis can reveal whether or not a fund given to a researcher has led to patenting, and (2) even though it is intuitive to think that there should only be a short amount of time between funding and patent filing, Daim *et al*. (2007) have found that the average time lag is 5 to 6 years. Keeping all the loops also helps us avoid the issue of falsely declaring a loop as being irrelevant; in fact, in most cases, it is nearly impossible by analyzing the content of each subject to tell whether the funds and patents are related[8].

It is important to mention that while a large portion of our data comes from an open source (i.e. the USPTO), we also have at our disposal information that is confidential in nature: the names of scientists receiving funds and more importantly, the amounts of each grant and contract given to these researchers. In order to respect these researchers' privacy, we censure their names, the amounts of funds they received and the number of patents on which they are listed as inventors.

Degree of application

We have acces to a classification of journals by CHI Research according to their degree of application[9], ranging from applied technology (1) to basic science (4). The degree of application is a concept we borrow from Hamilton (2003) but adapt here to our own needs. Considering that there is a given piece of knowledge associated to a specific patent that will, in many cases, be discussed in scientific papers by their inventors, it is possible to determine the degree of application of said knowledge with the data at hand. First, we match patent inventors from the USPTO database with article authors in the SCOPUS database using a similar procedure to the one used in the looping process. We then calculate the average degree of application of each journal in which the inventors of that patent published within 3 years of the patent application. The result is what we consider to be the degree of application of the patented knowledge. Although this may seem farfetched, it gives us an indication of the state of research in the lab during the time leading to a patent application.

FINDINGS & INTERPRETATION

In this section we explore similarities between nanotechnology and biotechnology, the importance of funding to patenting, the involvement of firms and scientists in comparing nanotechnology to biotechnology, and the nature of these collaborations.

[8] A classic example would be the grant or contract project title 'Ribosome studies', which appears to have no relevance to the patent title 'Catalytic DNA'.

[9] The classification distinguishes between biomedical fields and all the other disciplines. In the first case, the scores correspond to the following definitions of the journals' contents: 1 = clinical observation; 2 = clinical observation and investigation; 3 = clinical investigation; 4 = basic biomedical research. In the second case the correspondence is: 1 = applied technology; 2 = engineering science -technological science; 3 =applied research - targeted basic research; 4 = basic scientific research (Hamilton, 2003).

Nanotechnology and biotechnology similarity

Looking at various quality measures and the degree of application of the knowledge associated with patented inventions enables us to conduct an original similarity analysis between Canadian nanotechnology and biotechnology patents. As far as quality goes, when consulting Table 2 and Table 3, one can see that nanotechnology patents have statistically significant superior number of claims and number of citations after a five-year time lap. We use fixed timeframes because we do not want to introduce a supplementary bias in our analysis, i.e. considering the total amount of citations received by all patents would not be wise as older patents would obviously have more citations than younger ones even if they were of lower quality. This would suggest that they have a higher probability of enabling further innovations and are more frequently used to generate new patented inventions, i.e. that they are of higher quality.

When considering the degree of application of the knowledge associated to all Canadian patents (Table 2 and Table 3), we find that the published knowledge associated to nanotechnology is more applied than biotechnology. Even though these averages are statistically non equivalent, we consider the actual difference between both categories of patents to be minimal since the scale of journal degree of application employed here is discrete, ranging from 1 to 4.

Looping Process

By matching university scientist funding with ensuing patents, we are able to identify 1518 instances where funding has led to patenting in biotechnology and 1026 in the case of nanotechnology. Table 1 presents the summary statistics concerning these loops.

Table 1: Summary statistics of the Innovation loops

		Nanotechnology		Biotechnology		Nanobiotechnology	
Number of potential loops		1026		1518		673	
Number of funding/patenting organisations in loops		37		61		31	
		Canadian	Non-Canadian	Canadian	Non-Canadian	Canadian	Non-Canadian
	Number of firms	25	4(1)*	42	7(3)	24	2(1)
	Number of educational institutions	5	0	5	0	5	0
	Number of foundations, associations, societies	2	0	3	1	2	0
	Number of Health institutions	0	0	1	0	0	0
	Number of Provincial corporations	1	0	2	0	1	0
	Number of persons	0	0	0	0	0	0
Number of inventing scientists		62		151		44	
Number of patents developed through loops		157		291		109	
Average gap from funding to patent application		4.2 (4.9)**		4.3 (4.6)		3.5 (4.8)	
Average gap between funding and patenting		7.5 (8.2)		7.7 (7.9)		6.9 (8.2)	
Average number of loops per researcher		16.5		10.1		15.3	
Average number of loops per institution		27.7		24.9		21.7	
Number of funds given to researchers		325		691		211	
Amount of funds given to researchers		19 159 855$++		34 415 515$		14 865 294$	
Average value of funds		58 953$		49 805$		70 451$	

* Number in parentheses represents those that have both domestic and international affiliations and from which funding has been provided directly via an international source. ** Average gap between distinct list of funds and patents included in loops. ++ All funds are constant CAD $ of 2002, i.e. they are deflated by the consumer price index.

Importance of loops

In order to determine whether or not university research financing is as important for private innovation as it is thought to be, we start by examining the financed university researchers' contribution to patenting. As far as nanotechnology is concerned, the percentage of patented inventions that have been produced by at least one academic-inventor who has received funding from that particular patent assignee is somewhat limited. Figure 1 shows that the funding of university researchers has directly led to the patenting of 1% of the 1991 nanotech patents; this is a tangible contribution of university research funding. The involvement of these researchers follows an S curve peaking at a little less than 6% in 1999, decreasing to 1% in 2005 and then hovering around 3% in 2008. The biotech innovation loops arise a couple of years earlier, in 1989, and follows a similar S curve pattern peaking at close to 5% in 2006.

These results suggest that, in the case of both nanotech and biotech, surprisingly few of the university researchers that have obtained funding from institutions, firms or other organizations are named inventors on the patent of an invention that is owned by those funding organizations. With the importance of university/industry collaboration being recognized as a key factor in nanotechnology and biotechnology innovation, two science-based domains, one would expect a greater contribution from academic-inventors, but this evidently does not turn out to be the case in Quebec.

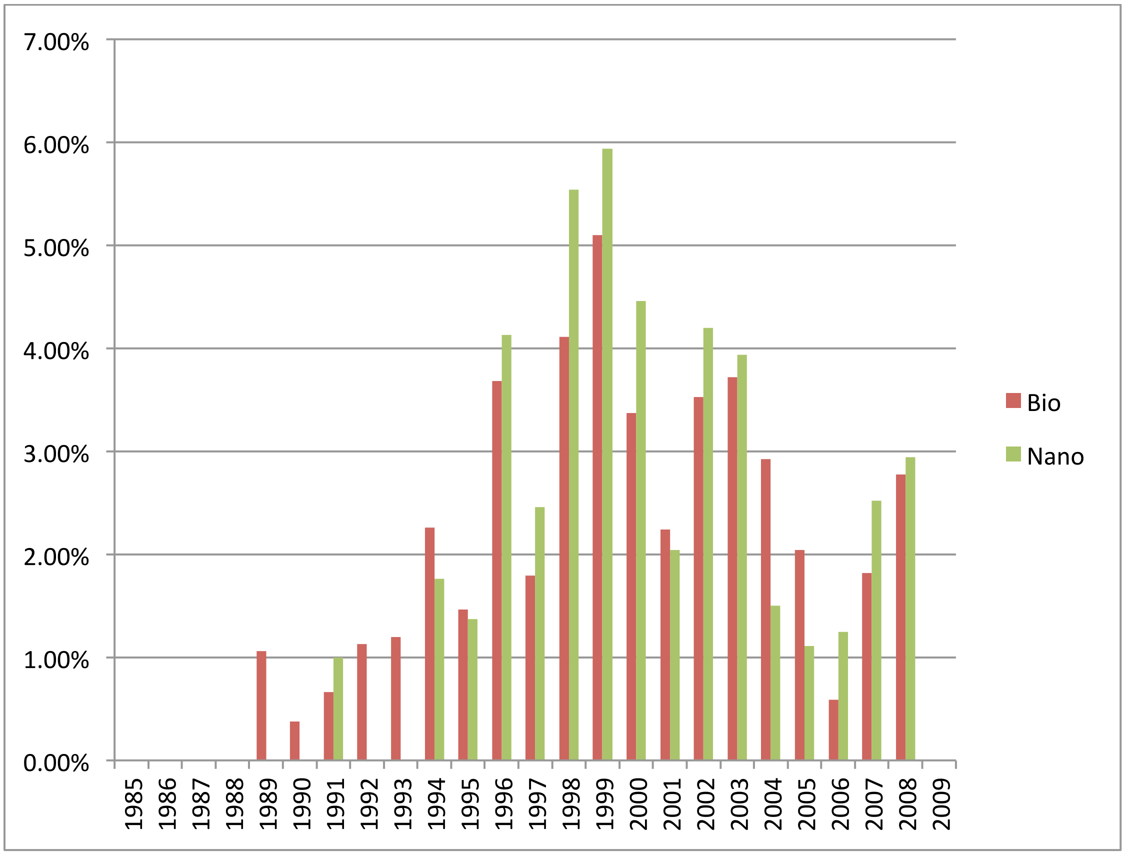

Figure 1: Percentage of patents that have at least one researcher who has received funding from the assignee

Firm involvement

Out of a total of 2545 individual biotechnology assignees of patents in our complete database, only 61 are included in our looping pattern. In other words, only 61 assignees have actually seen their funding of a Quebec university researcher lead to a patented invention where that researcher is a named inventor on the patent. Of those 61 assignees, 42 are firms, 5 are educational institutions, 3 are foundations, 2 are provincial corporations and 1 is a health institution. In the case of nanotechnology, there have been a total of 1251 patent assignees since the early 1980's, but only 37 of those are included in our loops, of which 25 are firms, 5 are educational institutions, 2 are foundations and 1 a provincial corporation. It is interesting to note that even though there are several thousand firms, foundations and institutions that have had ownership over nanotechnology and biotechnology patents, relatively few have funded university research that led to patents involving the researchers they have funded. On average, each institution involved in nanotechnology has participated in 27,7 loops, which is a little more that 24,9 of those participating in biotechnology. Furthermore, the average value of funds leading to patenting is slightly higher in nanotech than in biotech, with average funds of 58 953$ and 49 805$ respectively. These averages hide an overall increase in the average value of funds that were awarded to university researchers and that led to patenting. This can mainly be explained by the fact that, even though the annual number of funds awarded that led to patenting decreases after 1999, the actual amount of funding remains constant from 2002 on.

Scientist involvement

Our looping procedure reveals that there are 151 Quebec biotechnology scientists that have received funding and are listed as inventors on patents owned by organizations that have funded their research. In the case of nanotechnology, only 62 such inventors are identified, of which 44 are involved in nanobiotechnology. Compared to the actual number of university researchers who are responsible for a patented invention in either biotech or nanotech, this is low. In fact, we find that there are 786 distinct Quebec university researchers that are listed on biotech patents, whereas there are 394 in nanotech. In relative terms, this means that 19,2% of academic-inventors have actually received funds that led to patenting with the funding organisation, and only 15,7% of academic-inventors in nanotechnology have actively contributed to a patented invention for an organization that has funded them (or should we say that their contribution has been 'officially' recognised by that organisation).

Considering the claimed importance of university scientists in nanotechnology and biotechnology innovation, we would expect a higher proportion. Or should we? It is more plausible that organizations do not consider academics as a means of patenting, i.e. the purpose behind the funding of academics is still aimed at the development of basic research that does not necessarily lead to patenting.

Patent Quality

Finally, we examine if the patents that have been included in loops and are the result of collaboration between firms and university researchers are of higher quality than those that are out of these loops. Table 3 contains the average number of claims for patents that do not belong to loops, the average number of claims for patents excluding those belonging to firms in loops and the average number of claims for patents belonging to firms in loops. Very surprisingly, it seems that there are no exclusively nanotechnology patents (excluding nanobiotechnology) containing at least one university researcher that are owned by a firm. It is therefore not possible for us to compare the numbers of citations and the numbers of claims with biotechnology patents. We can however calculate the averages for biotechnology patents.

It seems that, in the case of biotechnology, patents that are born of financial collaboration between university researchers and firms have a higher average number of claims than those excluded from direct financial collaboration (Table 3). To avoid time related bias, the citation analysis uses a fixed timeframe to examine the difference in citation rates between patents excluded from loops and those included in loops. Our results suggest that patents that are part of loops involving industry funded university research consistently receive a number of citations that are not statistically different from those out of loops (Table 6). Taking the number of claims and the average citations into account, we can suggest that patents in loops of which the assignees are firms have a wider scope than those that are out of loops and also that they appear more crucial in enabling future innovation. This would entail that they are of higher quality.

Collaborations

Figure 5 and Figure 6 in Annex B, on researcher-funding organization partnerships, exhibit the classic Pareto's principle. Many of the university researchers that we find to be implicated in innovation loops seem to be recurring collaborators that are linked to several funds and patents, which one might suggest implies the Matthew Effect to some extent. This is to be expected since funding that leads to innovation often also leads to more funding (Van Looy *et al*., 2004). Firms prefer to collaborate with researchers who have already made a well-recognized discovery; they also give more to scientists with whom they already have a history of collaboration (Beaudry & Schiffauerova, 2011) to a certain extent, as this makes progress easier (Zucker & Darby, 1996). Furthermore, institutions that are involved in innovation loops also seem to be involved in recurring partnerships, that is to say there are few firms involved in a larger number of loops. This is normal since most firms are only willing to fund university research if they have some capability of appropriating the knowledge generated by the university researcher (Bonaccorsi & Piccaluga, 1994) and this is not the case of most organizations.

Degree of application

One of the critical aspects of interest is the effect of the length of the time interval between the actual funding of academic-inventors and the patenting that ensues. By using various measure limits to compare small time lags to large time lags, e.g. splitting the time lags according to the position from the mean, median, and quartile (Table 5 & Table 6), we find that there is no evidence supporting the assertion that an increased degree of application of the knowledge generated is associated with with a short time interval (between funding and patenting). That is to say, the knowledge published by researchers around the time when they received funds from firms and then have patented an invention based on said knowledge has been done so in journals that cover the same level of application no matter the patent category (i.e. nanotechnology, biotechnology or nanobiotechnology).

CONCLUSIONS

The number of instances in which a Quebec university researcher has received funding from an organization and contributed to an invention that was subsequently patented for that organization is surprisingly low, with a large part of these organizations being groups other than private firms. There are many possible reasons to explain this. First, organizations wishing to develop innovations aren't investing in university scientists' research. Second, scientists are receiving funds from various organizations that do not expect patenting in return, e.g. firms fund scientists in order to maintain links with the university milieu and more importantly with basic science as mentioned by Meyer (2006) and universities fund their scientists to help them increase their publications. Third, it is not so much the financial collaboration that leads to patenting as much as the knowledge collaboration although it is difficult to imagine university scientists in the fields of nanotechnology and biotechnology innovating without appropriate funding. Although nanotechnology and biotechnology share multiple commonalities, seeing how the size and nature of the loops differ according to their respective fields, it might be a mistake to replicate the biotechnology knowledge process in nanotechnology as it does not appear to be as efficient. In fact, the nanotechnology process might possess its own optimal innovation model. Thus, in order to extract constructive answers regarding this issue, further research is required.

Even though we have gone to great lengths to ensure that our scientists were appropriately matched with each other, it is most likely that we have (to some extent) included false positives in our looping process and excluded false negatives. This is even more relevant for assignees for which it is not uncommon to be represented over time by various names. Be that as it may, the rigor with which we have proceeded in creating these loops and the time devoted to that process greatly reduces the impact of these limitations. Further limitations include the fact that assignees can vary in time and also the fact that it is difficult to evaluate the weight of a given loop to determine it's importance in the innovation process.

Policy implications

With this project, we have mapped a portion of the innovation processes involving university researchers and funding institutions and it is important to note that this work can be taken as a guide for industrial policy concerning nanotechnology innovation, but also as a notice to those developing their institutions R&D policies. National development policies from public and institutions should also take this into account when considering how much and to whom they should award research grants.

Directions for future research

As interesting as our results appear, we feel as though they could be improved, therefore our next avenue of research is to enrich our innovation loop concept by integrating cases where university scientists have received funding by a firm and have co-authored an article with one of the firm employees who was subsequently listed as a patent inventor in their field of research. We would also like to determine whether or not university students who have received funding from industrial firms have gone on to work for them after their graduate studies and eventually developed a patented invention. This would give a good indication as to the long-term importance of funding in the development of scientific networks in biotechnology and nanotechnology. In short, there are many possibilities for future investigation and further researcher is evidently required to fully grasp the relationship between financing and innovation in the high-tech fields that are nanotechnology and biotechnology.

ANNEX A: COMPARISON STATISTICS

Table 2: Canadian patent quality and application indicators

		NANOTECHNOLOGY		BIOTECHNOLOGY				NANOBIOTECHNOLOGY	
		Average	n	Average (Set A)	n (Set A)	Average (Set B)	n (Set B)	Average	n
Average Nb of claims	Sample No								
	1	21.48748	3555	17.1562	3457	17.13156	2592	21.0637	2386
	2	-	-	17.44751	3477	17.00343	2625	-	-
	3	-	-	16.94838	3448	17.48483	2603	-	-
	4			-	-	17.11944	2562	-	-
	Total	21.48748	3555	17.18474	10382	17.18474	10382	21.0637	2386
Average Nb of citations after 5 yrs	Sample No								
	1	3.962818	3577	2.314154	3476	2.527245	2606	3.091514	2404
	2	-	-	2.444794	3496	2.285498	2641	-	-
	3	-	-	2.357287	3465	2.37782	2615	-	-
	4			-	-	2.298641	2575	-	-
	Total	3.962818	3577	2.372233	10437	2.372233	10437	3.091514	2404
Average degree of application	Sample No								
	1	3.04809	861	3.357732	590	3.366554	462	3.25215	802
	2	-	-	3.356374	606	3.333089	440	-	-
	3	-	-	3.374035	592	3.416018	446	-	-
	4			-	-	3.334097	440	-	-
	Total	3.04809	861	3.362669	1788	3.362669	1788	3.25215	802

In order to account for a potential effect the difference in size of compared populations could induce, we split the biotechnology dataset into comparable sized test samples. Set A is compared to nanotechnology and set B is compared to nanobiotechnology.

Table 3: p-values of quality and degree of application comparisons for H0: Equality of averages

		NANOTECHNOLOGY vs BIOTECHNOLOGY	NANOTECHNOLOGY vs NANOBIOTECHNOLOGY	BIOTECHNOLOGY vs NANOBIOTECHNOLOGY
p-value of nb of claims comparison	Sample No			
	1	****	**	****
	2	****	-	****
	3	****	-	****
	4	-	-	****
p-value of nb of citations comparison	Sample No			
	1	****	****	+
	2	****	-	+
	3	****	-	+
	4	-	-	*
p-value of average degree of application comparison	Sample No			
	1	****	****	***
	2	****	-	*
	3	****	-	****
	4	-	-	*

+ for p>0,10. * for p=<0,10. ** for p=<0,05. *** for p=<0,01. **** for p=<0.001

Table 4: Quebec firm owned patent quality indicators

		NANOTECHNOLOGY		BIOTECHNOLOGY		NANOBIOTECHNOLOGY	
		Average	n	Average	n	Average	n
Average Nb of claims	Category						
	In loop	24.04166	24	18.0125	80	19.46789	109
	Out of loop	-	-	16.19519	297	15.93043	115
	Total	24.04166	24	16.5808	377	17.6517	224
Average Nb of citations after 5 yrs	Category						
	In loop	2.458333	24	1.5625	80	1.66055	109
	Out of loop	-	-	2.053691	298	1.843478	115
	Total	24.04166	24	1.94974	378	1.75446	224

Table 5: Looped patents' degree of application according to time interval between funding and patent application

		NANOTECHNOLOGY		BIOTECHNOLOGY		NANOBIOTECHNOLOGY	
		Average	n	Average	n	Average	n
Split by mean	Category						
	T < mean	2.92227	16	3.36394	47	3.42066	59
	T > mean	2.82994	24	3.38103	30	3.25308	20
	Total	2.86687	40	3.37059	77	3.37824	79
Split by median	Category						
	T < median	2.93509	13	3.32785	34	3.42414	54
	T > median	2.83402	27	3.40440	43	3.27909	25
	Total	2.86687	40	3.37059	77	3.37832	79
Split by quartile	Category						
	lower quartile	3.03222	5	3.33587	25	3.64139	29
	upper quartile	2.89142	18	3.46657	24	3.11887	11
	Total	2.92203	23	3.39989	49	3.37824	40

Table 6: p-values of (1) quality and (2) effect of time interval on degree of application comparisons for H0: Equality of averages

		NANOTECHNOLOGY	BIOTECHNOLOGY	NANOBIOTECHNOLOGY
p-value of quality of Quebec patents (by looping category)	Average Nb of claims	N/A	**	+
	Average Nb of citations after 5 yrs	N/A	*	+
p-value of average degree of application comparison (by time interval)	Split by mean	+	+	+
	Split by median	+	+	+
	Split by quartile	+	+	**

+ for p>0,10. * for p=<0,10. ** for p=<0,05. *** for p=<0,01. **** for p=<0.001

ANNEX B: CHARTS

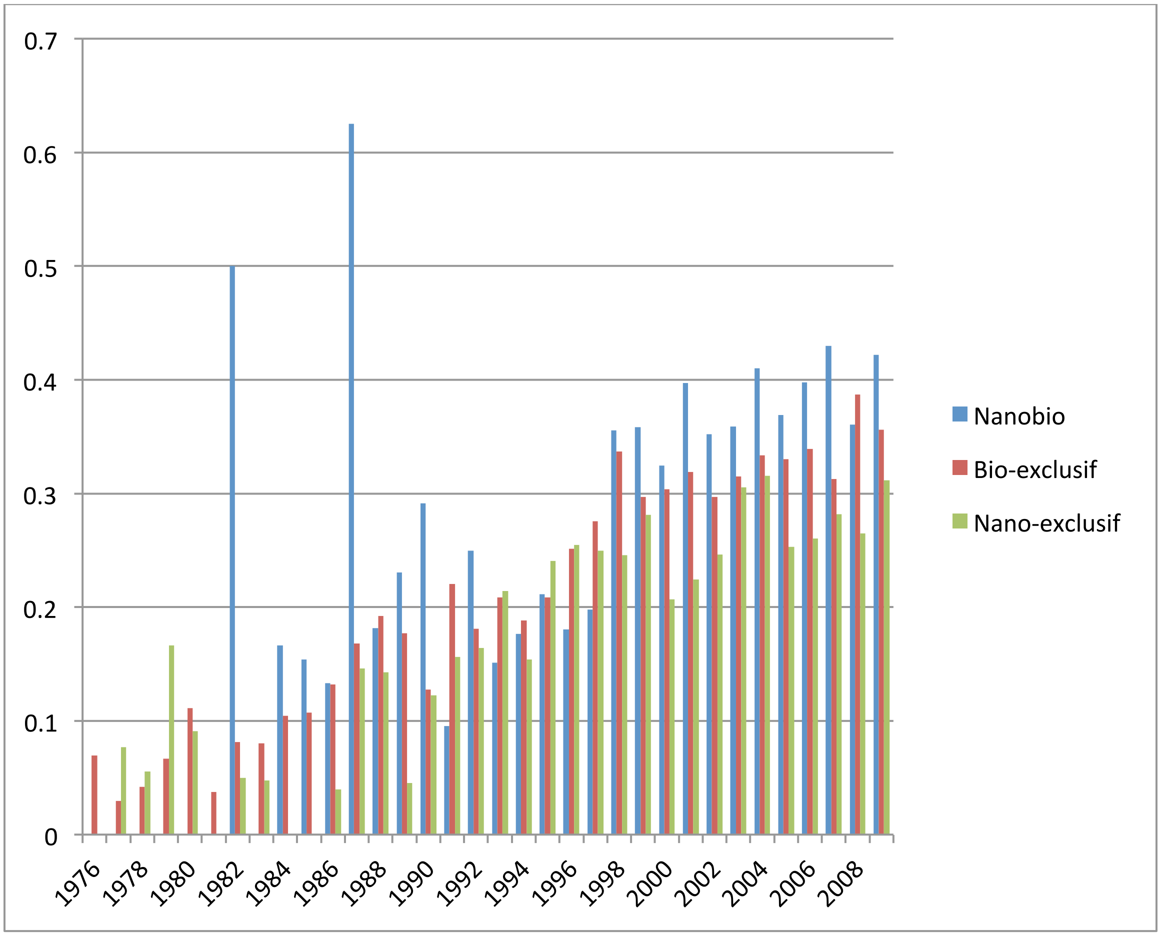

Figure 2: Proportion of patents with university researchers as inventors

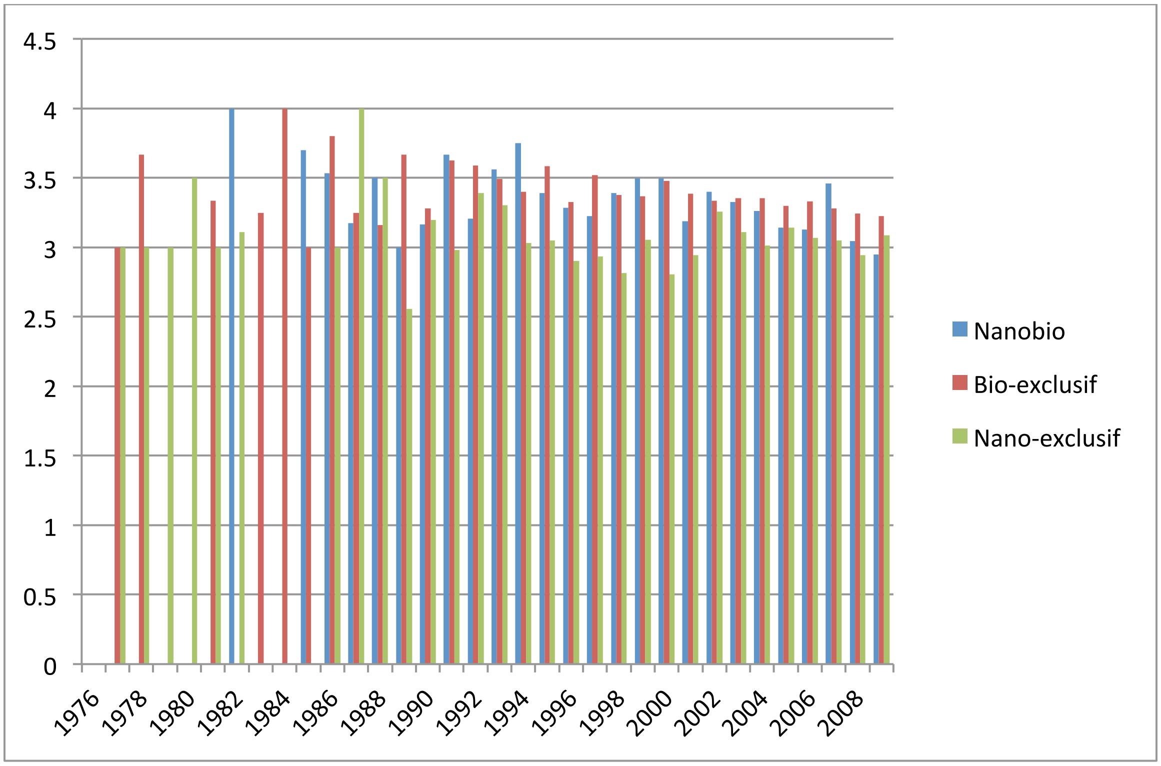

Figure 3: Average degree of application of knowledge associated to patented inventions

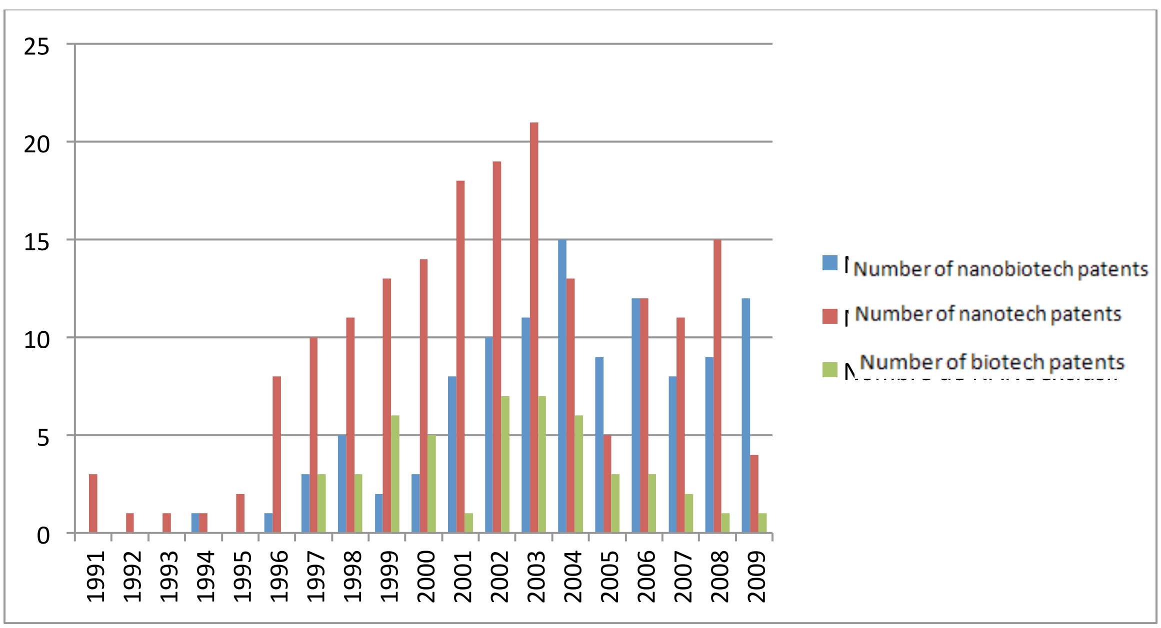

Figure 4: Number of patents derived from loops

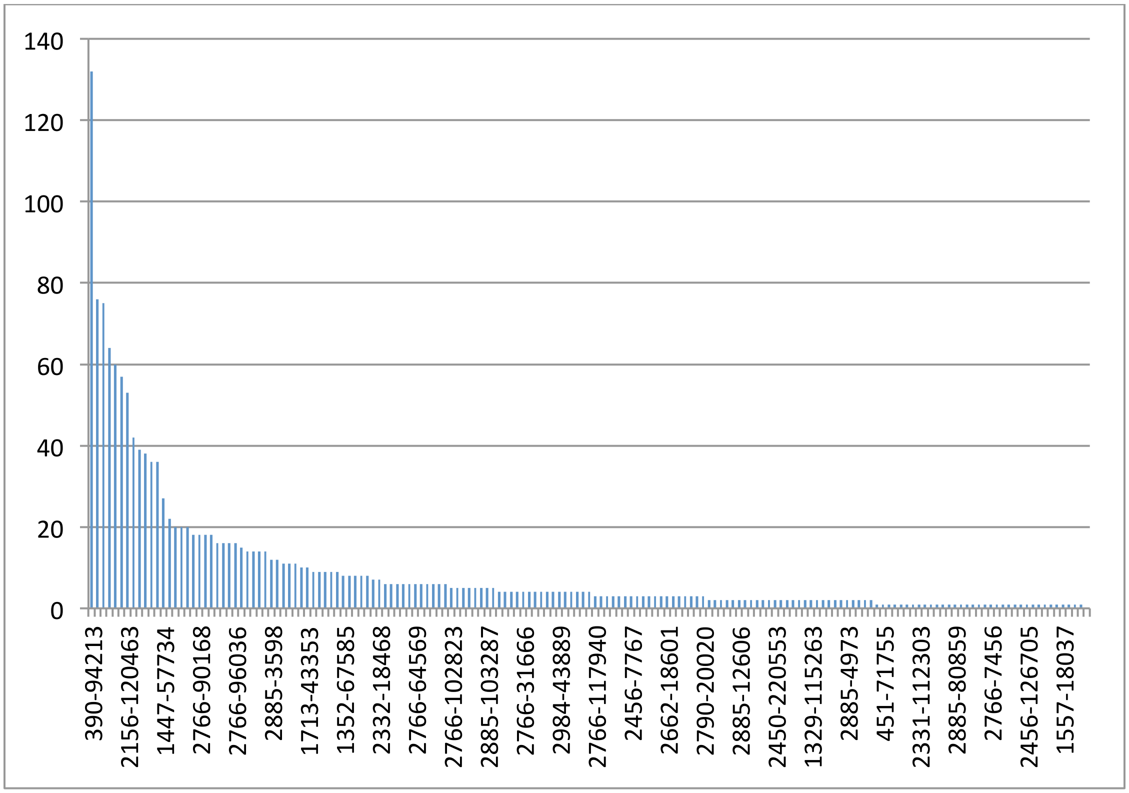

Figure 5: Biotechnology organization-scientist collaboration chart (nb of innovation loops per partnership)

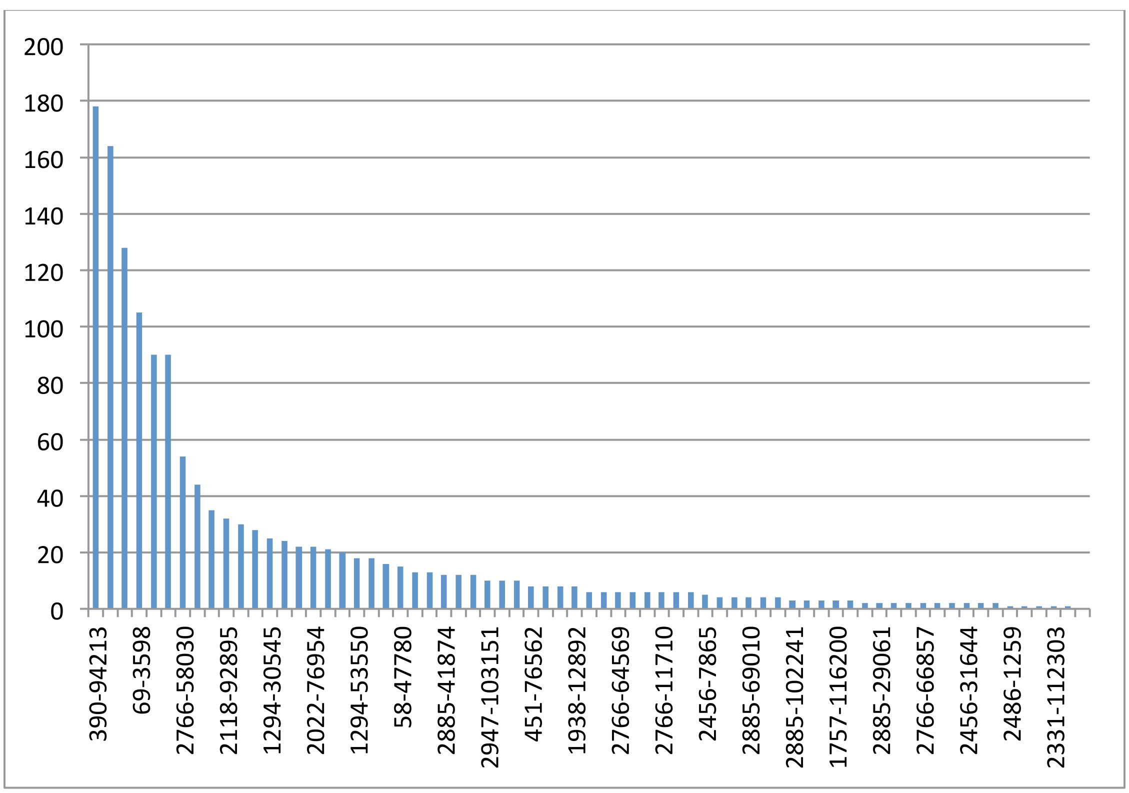

Figure 6: Nanotechnology organization-scientist collaboration chart (nb of innovation loops per partnership)

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