Impact of Research Funding on Nanobiotechnology Scientific Production: Does Concentration in a Few Universities Make Sense?[*]

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Abstract–**This study measures the impact of university-funded research and collaboration on scientific production of Canadian nanobiotechnology academics. This paper analyses a time-related model of the impact of academic research financing and network structure on research output measured by the number of papers and on the number of citations received by these publications. Results suggest that individual funding and a strong position in the past collaborative network has a positive effect on research output. In contrast to a number of studies, contracts are not found to have a negative influence on publication, quite the contrary. No impact of research funding is found on the number of citations received by an article.**

Index terms–**Innovation networks, social network analysis, research funding, scientific articles**

I. INTRODUCTION

The financing of university research is being scrutinised in Canada as governments increasingly demand measures of impact and outcomes from grant awarding bodies. As Gibbons *et al.* [27] suggest, the direction of research has migrated from a discipline-based science free of societal needs to a more demand driven science that must meet certain objectives. The integration of university research financing with government programmes aimed at the stimulation of innovation is a relatively recent phenomenon [40], but a strategy that is used more and more. This is especially true for domains seen as potential growth generators such as aerospace, biotechnology and lately nanotechnology. Innovation incentives such as R&D tax credits have

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been put in place and university researchers have benefitted from increased links with industry as a consequence.

Nanotechnology has potential applications in a wide range of domains, from nanomaterials to nanoelectronics, and from nanofoods to nanobiotechnology. Because of this intrinsic heterogeneity we have chosen to address nanobiotechnology, a field at the frontier of biotechnology and of nanotechnology. Nanobiotechnology innovation goes through different phases of development: from idea to output and finally to commercialisation. Each phase faces uncertainties, whether technological or commercial. For the first phase, from an idea to its output, the patience required and the uncertainties linked to the innovation process do not suit all types of fund providers [6], hence the importance of public research in these domains. As nanobiotechnology is a relatively new emerging technology, risks are inherent to its innovation process. Collaboration with university research centres contribute to reducing the uncertainties of innovation activities and thus the risks related to R&D projects. Public financing of research thus facilitates the production of knowledge and constitutes one of the key elements of the development of high-tech innovation. Research funding therefore enhances the success of innovation.

A recent debate [56] on university research funding in Canada saw the "big 5" universities (University of British Columbia, University of Alberta, University of Toronto, University of Montreal and McGill University) argue that they should receive all (or the bulk of) the research funding, concentrate only on graduate training and leave undergraduate teaching to the other Canadian universities. The reason put forward was almost as simple as *because we are the best at research*. Although this proposal raised a wall of protestation in Canada, the question as to where does research funding has the most impact deserves an answer. In this article, we focus on the Quebec universities and compare the publication results obtained by two of the "big 5" (University of Montreal and McGill university) as a result of the research funding received.

While public research grants are generally associated with wide scope projects, private contracts concentrate on short-term objectives aiming at the production of knowledge that can rapidly be used [30]. This paper aims at linking individual research grants and contracts to publication performance to measure the impact of nanotechnology research financing. Although it is not the prime aim of this paper to investigate whether contracts are detrimental to scientific publication performance, our model allows us to crudely contribute to the debate. All things being equal, we do not generally find that contracts have a negative effect on scientific production.

Instead, the issue that this paper wishes to discuss is the effect of the interaction between research funding and collaboration, in particular the position of an individual scientist within her co-publication network, on individual scientific production. Using a panel data negative binomial regression model, we show that researchers in more central and cliquish positions, with a greater number and amount of grants and contracts, publish more. And that this is true regardless of the university from which the publications emanate. We then add a measure of quality to the quantity of publications, using an index of the number of citations received for the articles published estimated from a panel data random-effect regression model. This therefore aims to show that more substantial grants help researchers publish research of a better quality.

This article thus integrates the literature on university research funding and on innovation networks. Using social network analysis of the co-authorship network of scientific articles, we aim to measure the spread of the nanotechnology knowledge base and its ramifications. Our goal is then to estimate the influence of publicly and privately funded research on the production of scientific articles controlling for the position of the researchers as well as the university affiliation of the scientists. The remainder of the paper is as follows: Section 2 describes the conceptual framework including a brief review of the literature; section 3 presents the data and methodology; section 4 presents various summary statistics of the data; section 5 discusses the regression results; and finally, section 6 concludes.

II. CONCEPTUAL FRAMEWORK

Biotechnology is a relatively young discipline consisting of a number of specialised sub-disciplines characterised by rapid knowledge diffusion [29]. A great number of scientific publications have been published in this domain during the last two decades. It is thus a multidisciplinary field that has created a rich pool of publications despite the fact that a large proportion of its knowledge base is mostly tacit and thus difficult to codify [2]. As technology permits and nanotechnology further develops, nanobiotechnology follows in the footsteps of biotechnology. Darby and Zucker [21] suggest that we can learn a great deal from the study of biotechnology and apply the findings to nanotechnology, as the two domains follow similar development and growth paths within two decades of each other. The observation of this rapid rate of growth in nanotechnology since 1990 is further supported by Bonaccorsi and Thoma [8].

Zucker et al. [63] insist on the necessity of collaboration between institutions to foster information exchange. Multi-project research centres force researchers and their universities to collaborate more efficiently using the diversity of resources available. Collaboration can indeed become a powerful lever to raise funds [20] and scientific collaboration and research funding are consequently intrinsically intertwined. If biotechnology research requires an important infrastructure in order to realise the projects that lead to the development of new products or processes, this is even more so for nanotechnology in general and thus for nanobiotechnology as well. Infrastructure investment not only consists of the acquisition of complex machines and instruments but also of the funds necessary for their operation and maintenance that requires specialised skilled personnel and logistics management to optimise access to this infrastructure. The creation of such a technological platform hence requires long-term investment in order to play its role as a space that fosters the emergence and fulfilment of new opportunities. Although universities and their affiliated research centres are the natural candidates for the localisation of such technological platforms, because their main goal is often to generate knowledge aimed at yielding technological innovation, the private sector should play an important role in their management and utilisation.

Intuitively, most university research projects are financed from public funds [33]. Hart [35] recognises that public financing is increasingly targeted towards the development of innovation according to specific political guidelines; the main objective of these political guidelines being the creation and maintenance of competence centres within the university network. This network composed of universities and their affiliated research centres, is an integral part of the national system of innovation [34]. Within the national system of innovation, universities and their affiliated research centres play a crucial role in the innovation value chain that leads to economic growth [40], [62]. For instance, universities are an important incubator of new biotechnology firms [44]. Public research infrastructure generates technological knowledge that is transferred via pure externalities, entrepreneurship or contracts [58], [61]. University researchers facilitate knowledge transfer between research laboratories and firms [5]. University spinoffs generate better innovations than large biotech firms [28]. Public research institutions play a key role both in the creation of new knowledge and of innovative local clusters of firms [23], [21], [60], [63] and in the retention of the most prolific researchers and students [26]. All these beneficial effects have a common origin: money and to a certain extent, collaborative work.

Payne and Siow [47] as well as Blume-Kohout et al. [7] suggest that the augmentation in public financing that university science research has experienced in the last decade has had a tremendous effect on scientific output. Furthermore, public funding for specific projects can be perceived as a signal of quality not only for the funded researchers, but also for their university. Adams *et al.* [1] show that top universities and departments that have earned awards, have larger teams (with an increased scientific division of labour at the international level) and have more government funding. In our analysis, we should probably find a strong relationship between the number of collaborators, the number and the amount of grants, and the generation of new knowledge measured by the number of scientific articles.

The granting of research money further act as a signal that attracts additional funding in subsequent years. Using a static model, Arora et al. [4] show that the publication track record of researchers has an influence on future grants and consequently on future publication levels as well. Zucker et al. [63] generally show the major impact that research financing has both on the publication of scientific articles and on patent production. A number of other scholars examine in greater details the number of publications emanating directly from specific grants. For instance, Payne and Siow [47] show that three years after receiving an instrumentation grant of one million dollars, between 8 and 11 new articles are generally published annually. Jacob and Lefgren [37] find that specific grants contribute to adding one additional publication with the five years subsequent to the attribution of the grant.

In a field as close to its science base as nanobiotechnology, public financing should be seen as complementary to private contracts. Private funding has dramatically increased since 1985 [13] and so did university-industry research centres. University-industry research relations increase contact with scientists but lower communication between scientists and possibly shield their work from potentials future partners [57]. As a consequence, a greater proportion of contracts for a particular researcher could have a negative effect on her future scientific production. This could be due to the different reward process used in industrial and academic milieus [46], or to the short-termism associated with private contracts [30]. We expect to find that contracts have a negative effect or at least a lesser effect on the knowledge production.

Knowledge used within these research institutions, is often appropriated from the publications generated by the research community [22]. Knowledge generated (output) by some scientists thus becomes knowledge appropriated (input) by other scientists. The notion of knowledge networks is clearly appropriate to the analysis of such a positive feedback, or virtuous circle, system. Their importance both in terms of economic growth and codified knowledge diffusion has been demonstrated [2], and a number of authors use social network analysis and network indicators emanating from graph theory to investigate the characteristics of groups of researchers [8]. Our research follows in their footsteps.

Nanobiotechnology university scientists do not generally work in isolation but in relatively large multidisciplinary research groups. Research funding is therefore rarely attributed to a single scientist, but much more commonly to a research team, especially when the amounts are rather large. The principle of collective invention as proposed by Allen [3] is very much a reality in this field. Lamoreaux and Sokoloff [39], Dahl and Pedersen [19], von Hippel [55] and Schrader [51] provide various examples of collective invention. This phenomenon is characterised by the free circulation of knowledge among socially connected agents. Social network analysis, as summarized by Cantner and Graf [11], has commonly been used to measure the degree of interrelatedness between these individuals [38].

Theoretical simulation studies have shown that knowledge diffusion is more efficient through clustered networks [15], and relatively cliquish networks [16]. The theoretical study of Cowan *et al.* [17] shows that network structure significantly influences the long-term production of knowledge. From an empirical point of view, Newman [44] shows that the probability of a particular scientist acquiring new collaborators increases with the number of his past collaborators, and that the probability of a pair of scientists collaborating increases with the number of other collaborators they have in common (the creation of a clique). Our paper examines these issues from an empirical point of view.

A number of scholars claim that collaboration persistency through time also positively influence knowledge productivity. For instance, Cowan *et al.* [17] claim that previous collaborations increase the probability of a successful collaboration in the future. Furthermore, Fleming *et al.* [24] argue that an inventor's past collaboration network will strongly influence subsequent productivity.

Newman [42] compared the co-authorship network structures of four databases of scientific papers in physics, biomedical research and computer science. In a subsequent article, Newman [43] observed that for most scientists, the path linking them to other scientists goes through a relatively small number of very central individuals. These central individuals generally receive the most research funding. The question therefore is whether the position and funding of these individuals influence their knowledge production. These are issues that we wish to address in this paper.

While the impact of network position and funding on scientific production seem obvious, can we extend this impact to the 'quality' of this research production? It is farfetched to actually link citations to the quality of the research. Bronmann and Daniel [10] wrote an excellent review of the division in two camps of the scientists interested in measuring impact: those that believe that citations are a useful assessment tool, and those that do not. Van Raan *et al.* [54], being part of the first group, suggest that high quality work should gain more citations from colleagues than low quality work. But what we really measure is the "utility within research" [52], the importance of scientific work [31] and its impact [25], [14] not necessarily its quality, citations are proxies [18]. Taking into considerations the doubts of the other camp (see for example [59]), we will treat the number of citations as a measure of the usefulness of a publication.

III. DATA AND METHODOLOGY

This project requires the integration of two sources of information, individual university researchers' funds and their position in the network of nanotechnology scientists. Two databases are used for this project: Elsevier's Scopus and the *Système d'information sur la recherche universitaire* (SIRU) of the Quebec ministry of education, leisure and sports. Scopus provides the necessary data on nanobiotechnology scientific articles (date of publication, co-authors and their affiliations), where nanotechnology is defined by a keyword search similar to that of Porter *et al.* [48]. We define nanobiotechnology the articles that are in the intersection between biotechnology (from previous research) and nanotechnology research. We have extracted all scientific articles relating to nanobiotechnology for which at least one Canadian-affiliated scientist contributed for the period 1952-2006. SIRU contains the grants and contracts during the period 1985-2005 of all Quebec university scientists, from which we extracted information for the nanobiotechnology scientists identified in the article search. The data for each scientist provides their affiliation as well as the yearly amount received from each grant or contract registered with the university[1]. Merging the two databases required the careful examination of the surnames and first names (in SIRU) or initials (in Scopus) of scientists and their affiliations in both databases[2]. The intersection of the two databases results in the scientific production and financing of all Quebec biotechnology academics.

Using the social network analysis software Pajek, we then build the network of co-authors using co-publication links between scientists. In these networks, the vertices are the co-authors or scientists and the edges between the vertices represent the co-authorship links of each article. In order to follow the evolution of collaboration over the years, we have created sub-networks using the co-publication links over periods of 3 years and 5 years. An analysis of these sub-networks enabled us to describe their structural properties and to explore the collaborative behaviour of nanobiotechnology scientists in Quebec.

Our measures of network attributes focus on a scientist's position within the network: degree centrality, betweenness centrality and individual cliquishness. Degree centrality of a vertex (scientist), or simply the degree of the vertex, is defined as the number of co-authors of a scientist in each sub-network [*degcentind*]. The scientists with the highest values of degree centrality are found in the most central positions of the network. They are directly connected to more scientists and thus have access to more potential knowledge sources and have better opportunities to spread knowledge. Betweenness centrality of a vertex (scientist) refers to the capacity of a scientist to link two other scientists from the same sub-network through the smallest number of intermediaries [*betcentind*]. If a greater proportion of the shortest paths between all other vertices "goes through" a particular vertex, this vertex has a higher betweenness centrality and her role as an intermediary is more important. Finally, cliquishness of a vertex is measured by the egocentric density of a vertex which is defined as the fraction of all pairs of the immediate neighbours of a vertex that are also directly connected to each other. The cliquishness [*cliqueind*] basically measures the likelihood that two vertices that are connected to a specific third vertex are also connected to one another, hence forming a clique.

One remaining question concerning the network measures relate to the time period covered by these networks. In other words, what is the historical structure of the collaboration that we should consider? One the one hand, public grants are generally awarded for a number of years. For example, Tier I Canada research chairs are generally awarded for periods of 7 years (5 years for Tier II chairs). Ordinary research grants vary from 3 to 5 years. Other major collaborative

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[1] A number of Quebec scientists own small company through which they perform consultative work. We have no means by which to estimate the breadth of such a practice but estimate it to be relatively small compared to the bulk of the funding received through the official channels, because of the very nature of biotechnology research.

[2] A common ambiguity in the Scopus database consists in attributing all the affiliations in a paper to each and everyone of the scientists.

grants cover 7 years of funding while smaller initiatives can be awarded for periods as short as one year. On the other hand, in the literature, the time period of collaborative networks vary from one study to the next. For instance, Schilling and Phelps [50] use three-year windows for their firm collaborative networks. Gulati and Gargiulo [32] prefer five-year windows and so does Stuart [53] but with a one-year lag. As a consequence, during the course of our analysis, 3- and 5-year sub-networks have been considered and the most robust results will be reported in this paper.

As mentioned above, one of the goals of the project consists in determining whether more innovation in generated by researchers with a greater number of grants or contracts and in more central positions. Our model will therefore be the following:

$$\begin{aligned} A_{it} = {} & \alpha + \beta_{G\#} nbgrantX_{it-l} + \beta_{GS} avergrantX_{it-l} \\ & + \beta_{C\#} nbcontX_{it-l} + \beta_{CS} avercontX_{it-l} \\ & + \beta_{C\#} nbcontX_{it-l} \times d_{91-93} + \beta_{CS} avercontX_{it-l} \times d_{91-93} \\ & + \sum_{m} \gamma_m INI_{imt-l} + \sum_{u} \mu_u dU_{iu} + \delta_t d_{85-95} + \nu_i + \varepsilon_{it} \end{aligned} \tag{III.1}$$

where A_{it} represents the number of articles of scientist *i* in year *t*; $nbgrantX_{it-l}$ is the number of grants obtained by scientist *i* from years *t-l-X*[3] to *t-l*; $avergrantX_{it-l}$ is the average yearly amount of grants (deflated by the consumer price index) obtained by scientist *i* from the years *t-l-X* to *t-l*; $nbcontX_{it-l}$ is the number of contracts obtained by scientist *i* from years *t-l-X* to *t-l*; $avercontX_{it-l}$ is the average yearly amount of contracts (deflated by the consumer price index) obtained by scientist *i* from the years *t-l-X* to *t-l*; d_{9193} is a time dummy variable that takes the value 0 for the period 1991-1993 where a surprising amount of contracts were awarded and the value 1 otherwise, this interactive dummy therefore aims at removing these problematic years for the contracts; INI_{imt} represent the characteristic *m* of the network position of scientist *i* in year *t* [*m* being *degcentindN* or *betcentindN* and *cliqueindN* and *N* taking the value 3 for here-year networks and 5 for five-year networks]; dU_{iu} are dummy variables for the university *u* to which scientist *i* belongs[4]; d_{85-95} is a dummy variable taking the value 1 for the period 1985-1995[5]; and $\upsilon_i + \varepsilon_{it}$ is the error term.

Fig. 1 shows that for the period 1991-1993, trend in contracts increases dramatically. According to Yves Gingras of the Observatoire des Sciences et Technologies, this corresponds to a period where a loophole in the law was overexploited by firms. The interactive dummy variable, d_{91-93}, simply removes these problematic years from the regression. Other interactive dummy structures were investigated but the results were not as good as this simpler method.

Our analysis has considered a lag structure of 1-, 2- and 3-year lags for most variables of the model, similar to what [50] have used in their model. We have tested all combinations of lags and the most robust results combine 1- and 2-year lags. Only the most robust results are

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[3] X represents either 3 or 5 years; l represents yearly lags of 1 or 2 years.

[4] We have not yet tracked down all the migrations of scientists across universities. So in this model, scientists are affiliated to their most common university.

[5] 1996 marks the year when Scopus increased significantly the number of journals covered. This period also corresponds to the moment when university reporting the ministry of education became compulsory.

presented in the paper. This panel data negative binomial regression model is estimated using the *xtnbreg* procedure of Stata 10.

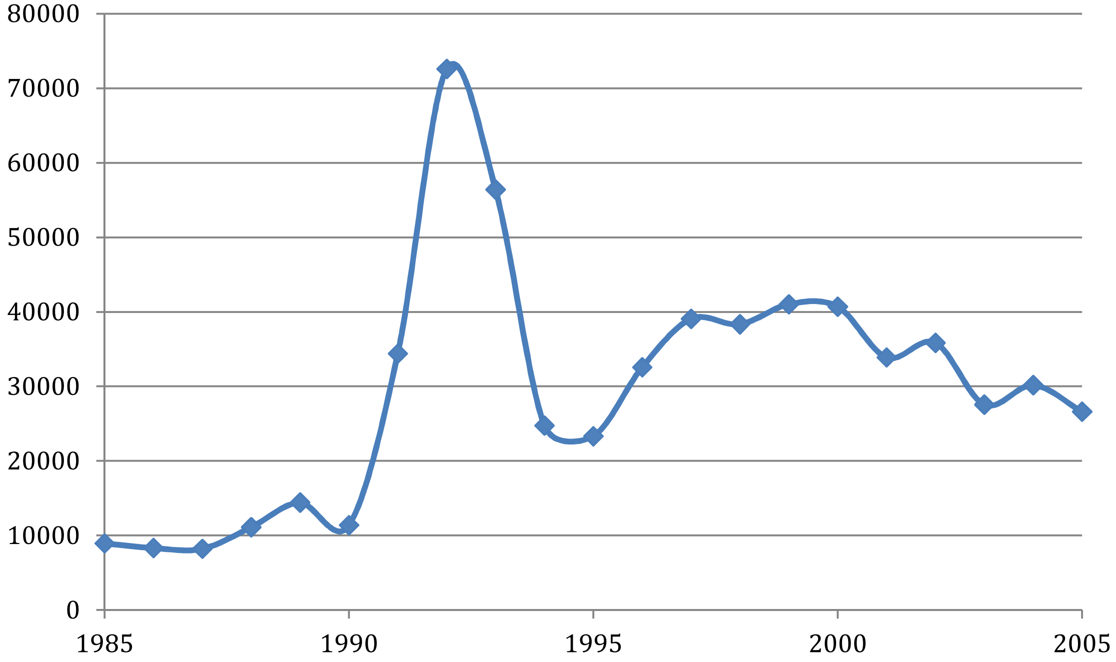

Fig. 1 Average amount of contracts (constant[6] Canadian dollars of 2002) received per scientist per year

A second model will take into consideration the number of citations received within the first three, five and seven years of publication, *nbcitY*, *Y* taking the value 3, 5 or 7. This measure will therefore replace A_{it} in equation (1). Although this may seem as a relatively short period to cumulate citations, this allows us to include the publications of 2004 and examine 20 years of nanotechnology research (from 1985-2004[7]). A number of variations of this measure were used. First, a very crude measure will sum the total number of citations received in the three to seven years following publication of the articles published by an individual in a given year and take the natural log of the total. A second variation using a relative index, comparing the total amount of citations received three to seven years following publication of the articles published by an individual in a given year divided by the mean of this value was also examined[8]. These models will be estimated using the *xtreg* procedure of Stata 10.

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[6] All amounts of funds have been deflated by the consumer price index, CPI.

[7] For citations 7 years after publications, the sample will of course stop in 2002).

[8] A number of variations of the dependent variable were used for instance the average number of citations per article, and normalised values dividing each measure by the mean of the university, cluster or country. None of these yielded good results and will not be presented in this paper.

$$
\begin{aligned}
nbcitY_{it} = {} & \alpha + \lambda_a A_{it} + \beta_{G\#} nbgrantX_{it-l} + \beta_{GS} avergrantX_{it-l} \\
& + \beta_{C\#} nbcontX_{it-l} + \beta_{CS} avercontX_{it-l} \\
& \left[+ \beta_{C\#} nbcontX_{it-l} \times d_{91-93} + \beta_{CS} avercontX_{it-l} \times d_{91-93} \right] \\
& + \sum_m \gamma_m INI_{imt-l} + \sum_u \mu_u dU_{iu} + \delta_t d_{85-95} + \nu_i + \varepsilon_{it}
\end{aligned}
\tag{III.2}
$$

Because we are interested in the effect that universities may play on the performance of individuals, a fixed effect model is not appropriate as the vast majority of our scientists do not migrate from one university to another and hence, these dummy variables are time-invariant. These time-constant variables are thus perfectly correlated with the dummy variables used for the fixed-effects. The random-effect model does not have this problem. The use of the random-effect model must however be tested using the Breusch-Pagan test [9] as well as the Hausman [36] specification test. Unfortunately, the Hausman specification test systematically rejected the random-effect model when using the relative index as a dependent variable, and as a consequence this model will not be presented here. In addition, although were replicated the analysis for three-, five- and seven-year citations, only the five-year citation regressions will be presented in this chapter as the results are similar.

IV. DESCRIPTIVE STATISTICS

Before turning to the regression results, let us first briefly present the descriptive statistics of some of the variables that will be used in these regressions. Our two dependent variables, the number of articles published and the number of citations they have received, are presented in Fig. 2 and 3. Because we are interested in two of the ‘big 5’ universities in the country, McGill University and the University of Montreal are included in both pictures. As the field of nanobiotechnology developed, the number of articles and of citations has considerably increased over the years. McGill University clearly dominates in terms of scientific production (in the recent part of the sample) and in terms of the quality of the research produced. For the university of Montreal though, the picture is not that of a world leader in the field. Further information is thus needed to understand why that may be so.

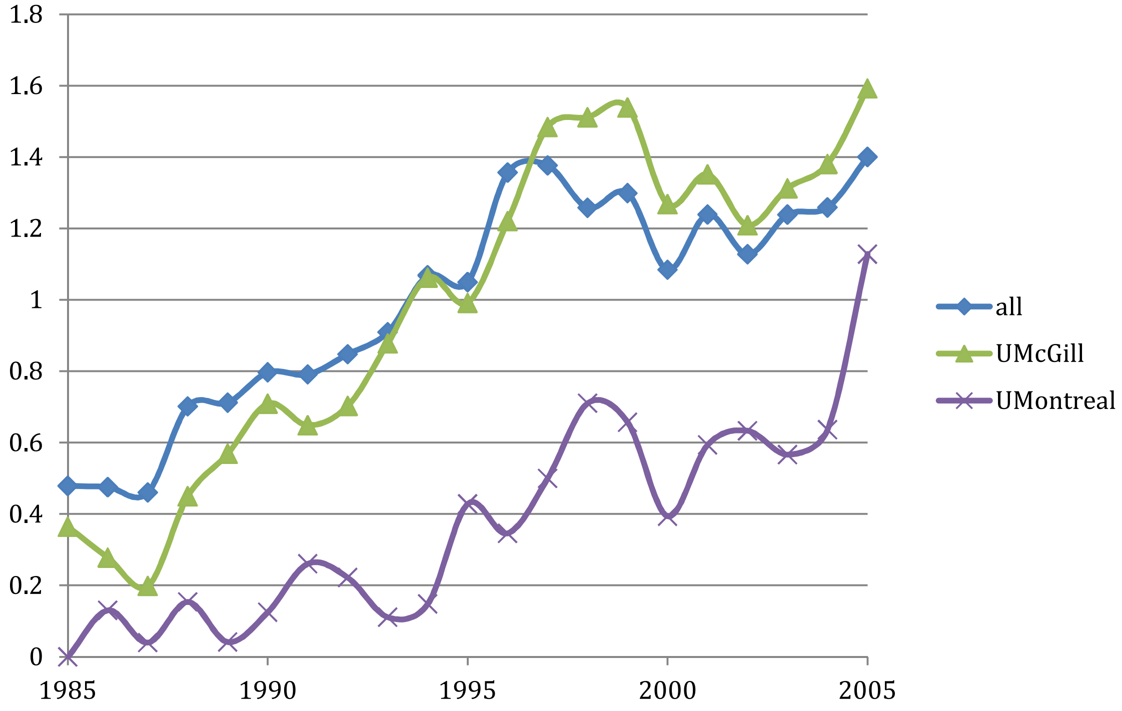

Fig. 2 **Average number of articles published per year**

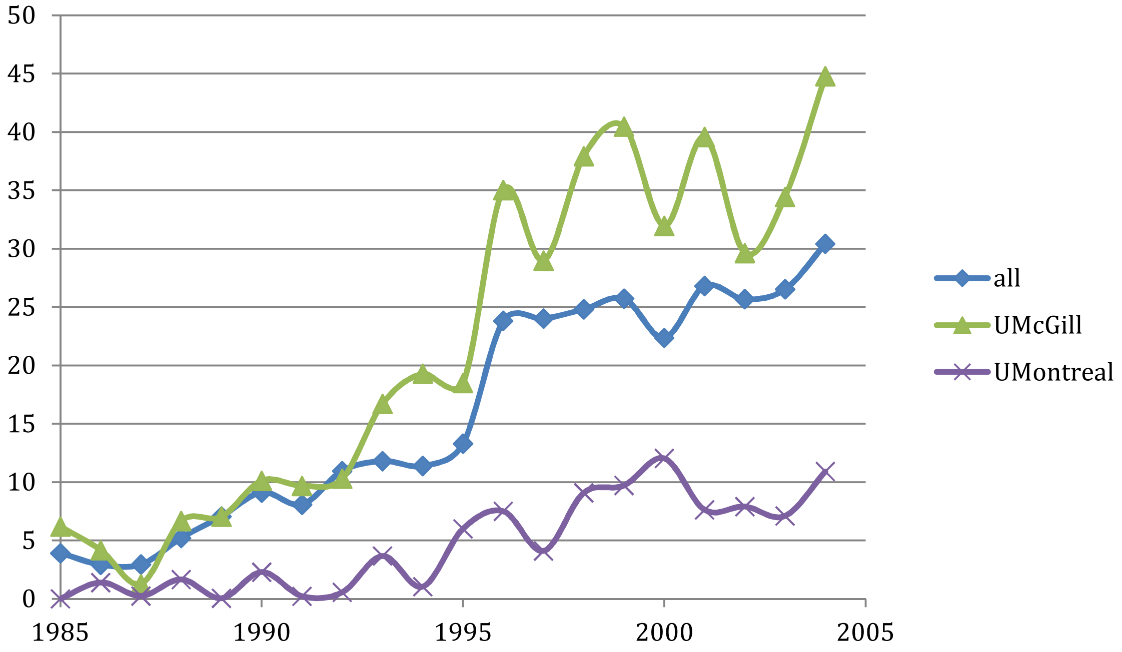

Fig. 3 **Average number of citations received for the articles published at time *t*, in the five years following publication**

Examining the average amount of research funds granted to individual researchers (Fig. 4), we show that until the mid-1990s, scientists from the University of Montreal receive less funds per year than their colleagues in other universities. Then, with the recruitment of new professors and the use of the Canadian foundation for innovation (CFI), the University started to build considerable research infrastructure. The recent increase in scientific production is probably attributable to this investment. Unfortunately, citations do not appear to follow this trend. Could it be that the research infrastructure in place also contributes to industry in the form of more applied research, and hence less 'citable'? Fig. 5 indicates that researchers from the University of Montreal have received on average more industrial contracts than McGill or the other universities (with the notable exception of Laval University). This would tend to suggest more applied work for/with industry.

Turning now to the network measures, we find that there has been a tendency towards convergence of the average degree and betweenness centrality as well as of cliquishness (Fig. 6). As more scientists enter the field of nanobiotechnology, the average network measures decrease. From 2003, however, the trend seems to be reversing as collaboration becomes established and the newly arrived scientists get better integrated in the network. More research is needed to establish whether this is a steady trend.

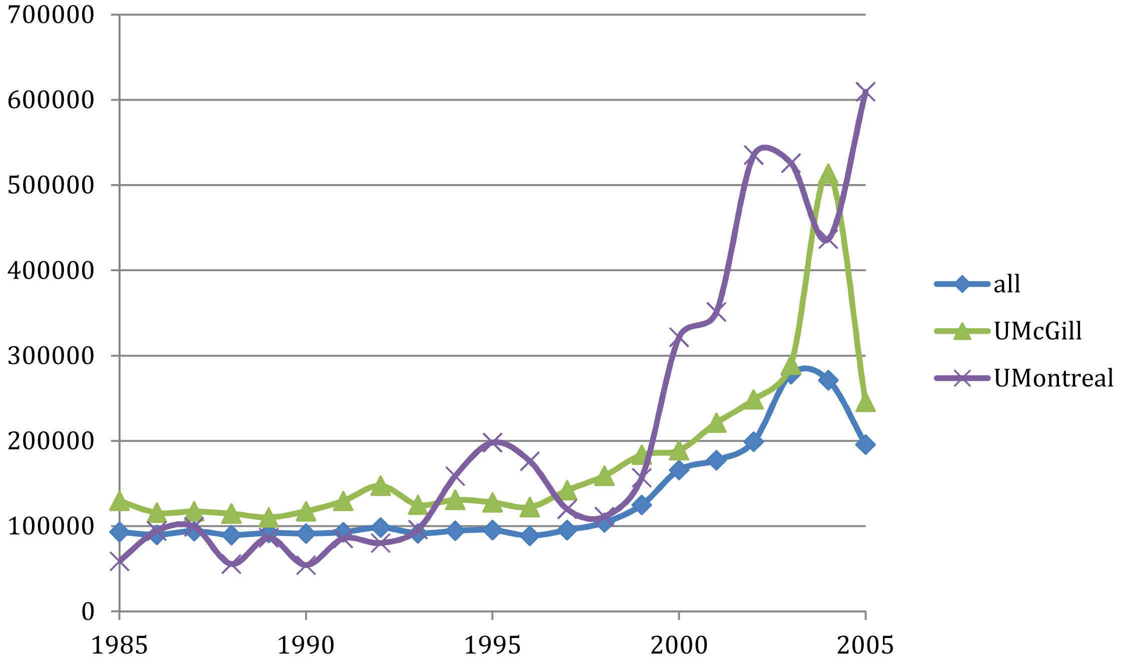

Fig. 4 **Average amount of public funds received (in constant Canadian dollars of 2002) per year**

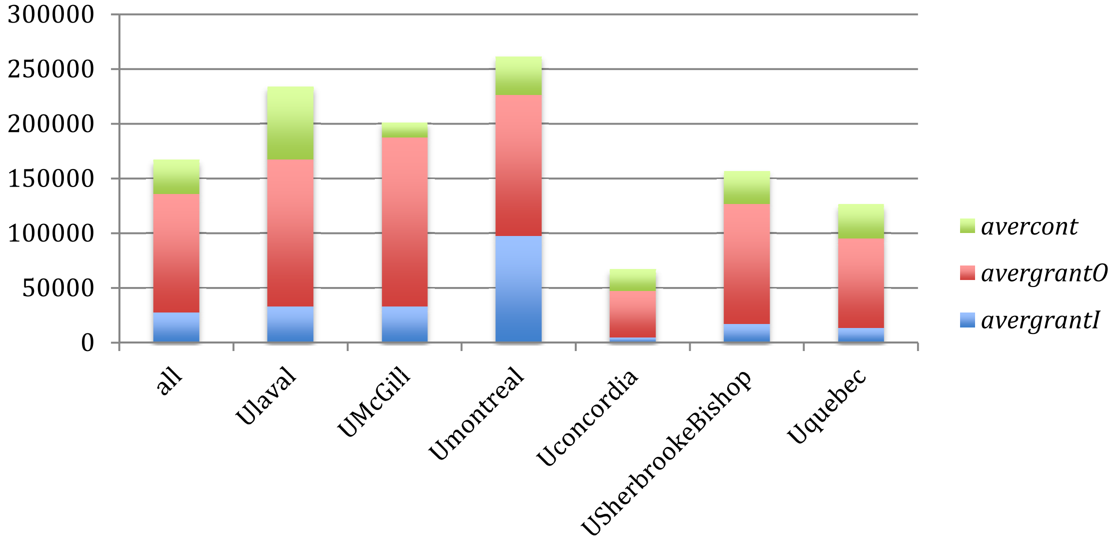

Fig. 5 **Average amount of public (Operating costs and Infrastructure grants) and private (Contracts) funds received (in constant Canadian dollars of 2002) per year**

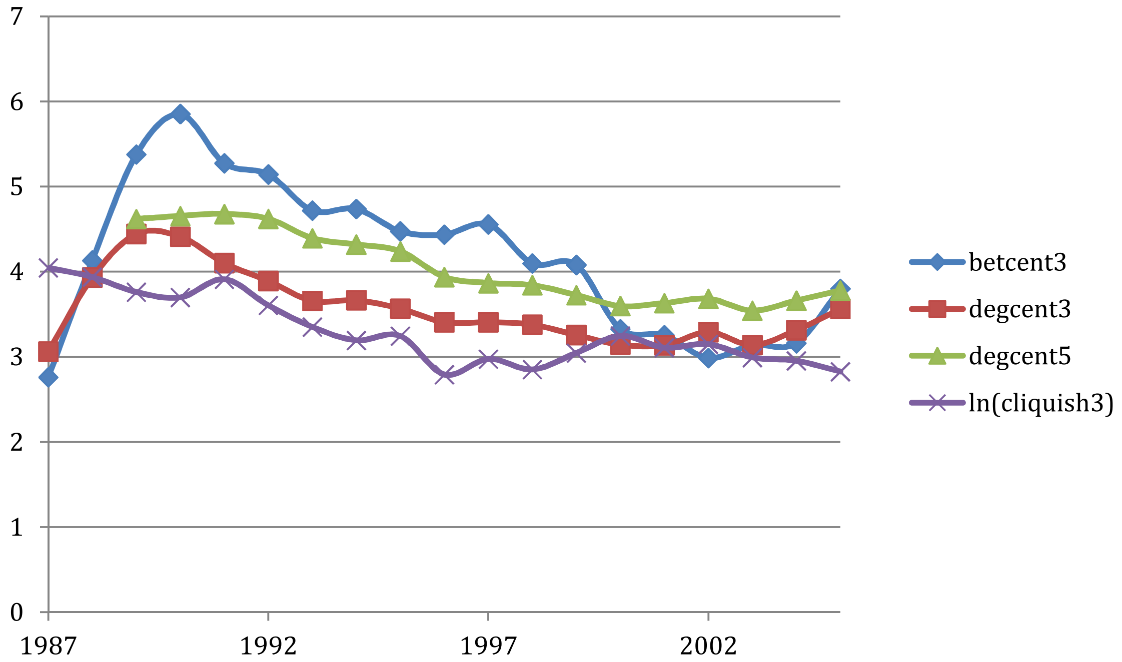

Fig. 6 **Average degree centrality for three-year and five-year networks (10 000 x *degcent3* and 10 000 x *degcent5*), betweenness centrality (10 000 x *betcent3*) and cliquishness (ln(1 000 x *cliquish3*) per year**

V. RESULTS

The regressions to be considered estimate the factors that influence researcher productivity in terms of the number of articles (the results are shown in Table 1). Only the most robust regressions with the most significant results are presented in this paper. As mentioned before, a variety of lag structures was tested (one-, two- and three-lags) in order to investigate the most appropriate time lags for each variable. The results shown in Table 1 are those for which the coefficient obtained for each variable is the most significant (two-year lags were found to be more appropriate for public grants, while one-year lags yielded more robust results for contracts).

Table 1 presents the results of 6 regression models, using a number of variables to represent grants, contracts and network position indicators. To facilitate interpretation, the coefficients are presented as incidence rate ratios (IRR). For instance, in model (1), if a researcher were to receive one more grant in a period of three years, his rate of articles would be expected to increase by a factor 1.0073, while holding all other variables in the model constant. The interpretation for the variables for which we have taken the natural logarithm is slightly different. Considering from Table 3 that the average value for the log of *avergrant3* is about 12.3, a one unit increase in the log, the rate of articles would thus be expected to rise by a factor of 1.006, *ceteris paribus*. Nearly all variables included in the 6 models, have a positive effect on the yearly production of scientific articles.

Table 1 – Regression results – number of articles per author per year

	(1)	(2)	(3)	(4)	(5)	(6)
$nbgrant3_{t-2}$	1.0073 ***	1.0068 ***	1.0087 ***			
	(0.0014)	(0.0014)	(0.0014)			
$nbgrant5_{t-2}$				1.0052 ***	1.0047 ***	1.0061 ***
				(0.0010)	(0.0010)	(0.0010)
$ln(avergrant3_{t-2})$	1.0068 *	1.0053	1.0066 *			
	(0.0036)	(0.0036)	(0.0036)			
$ln(avergrant5_{t-2})$				1.0075 **	1.0059	1.0075 *
				(0.0038)	(0.0038)	(0.0039)
$nbcont3_{t-1}$	1.0110 ***	1.0108 ***	1.0114 ***	1.0108 ***	1.0107 ***	1.0111 ***
	(0.0028)	(0.0029)	(0.0028)	(0.0028)	(0.0029)	(0.0028)
$ln(avercont3_{t-1})$	1.0006	1.0007	1.0014	1.0004	1.0005	1.0011
	(0.0029)	(0.0030)	(0.0030)	(0.0029)	(0.0030)	(0.0030)
$nbcont3_{t-1}$ x d_{9193}	0.9920 *	0.9927 *	0.9917 **	0.9920 *	0.9927 *	0.9917 **
	(0.0042)	(0.0042)	(0.0042)	(0.0042)	(0.0042)	(0.0042)
$ln(avercont3_{t-1})$ x d_{9193}	1.0209 ***	1.0150 ***	1.0202 ***	1.0208 ***	1.0153 ***	1.0201 ***
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
10^4 x $degcentind3_{t-1}$	1.0368 ***			1.0368 ***		
	(0.0024)			(0.0024)		
10^4 x $degcentind5_{t-1}$		1.0416 ***			1.0415 ***	
		(0.0026)			(0.0026)	
10^4 x $betcentind3_{t-1}$			1.0074 ***			1.0074 ***
			(0.0006)			(0.0006)
$ln(10^3$ x $cliquind3_{t-2})$	1.0564 ***	1.0446 ***	1.0903 ***	1.0564 ***	1.0449 ***	1.0905 ***
	(0.0112)	(0.0114)	(0.0114)	(0.0112)	(0.0114)	(0.0114)
dULaval	1.0868 *	1.0804 *	1.0844 *	1.0854 *	1.0783	1.0828 *
	(0.0510)	(0.0508)	(0.0523)	(0.0509)	(0.0507)	(0.0522)
dMcGill	1.0840 *	1.0763	1.0854 *	1.0853 *	1.0776	1.0862 *
	(0.0507)	(0.0502)	(0.0522)	(0.0507)	(0.0503)	(0.0522)
dConcordia	1.0194	1.0307	1.0219	1.0207	1.0313	1.0235
	(0.1064)	(0.1069)	(0.1106)	(0.1067)	(0.1072)	(0.1109)
dSherbrookeBishop	1.0816	1.0516	1.0812	1.0811	1.0509	1.0809
	(0.0740)	(0.0722)	(0.0757)	(0.0740)	(0.0721)	(0.0757)
dUQuebec	0.9885	0.9805	0.9916	0.9871	0.9782	0.9903
	(0.0528)	(0.0524)	(0.0543)	(0.0528)	(0.0523)	(0.0543)
$d_{1985-1995}$	0.7018 ***	0.7330 ***	0.6959 ***	0.7105 ***	0.7383 ***	0.7060 ***
	(0.0197)	(0.0213)	(0.0198)	(0.0203)	(0.0216)	(0.0203)
ln(r)	2.7694	2.8251	2.6557	2.7686	2.8223	2.6547
	(0.0818)	(0.0843)	(0.0796)	(0.0818)	(0.0843)	(0.0796)
ln(s)	1.2627	1.3001	1.1324	1.2642	1.2991	1.1346
	(0.0677)	(0.0697)	(0.0635)	(0.0676)	(0.0695)	(0.0635)
n	10039	9775	10039	10042	9778	10042
n_{groups}	1168	1162	1168	1168	1162	1168
average nb years	8.6	8.4	8.6	8.6	8.4	8.6
max nb years	17	16	17	17	16	17
Log likelihood	-15457.6 ***	-15091.9 ***	-15491.7 ***	-15462.5 ***	-15097.8 ***	-15497.0 ***
Wald χ^2	720.34	670.78	635.32	721.37	668.87	635.04
LR test vs pooled: $\bar{\chi}^2_1$	1453.51 ***	1399.07 ***	1793.44 ***	1455.23 ***	1404.85 ***	1795.8 ***

Notes: ***, **, * show significance at the 1%, 5% and 10% levels respectively.
Standard errors are presented in parentheses
All coefficients are presented as incidence rate ratio (IRR) to facilitate interpretation

The results on contracts do not have the expected negative effect anticipated from the literature, if we were to assume that scientists that obtain industry contracts patent or are distracted by very applied or less publishable research. This does not seem to the be the case as the number of contracts has a positive effect on the number of publications while the amount received on average does not influence the publication level. This may be a field effect. Indeed nanobiotechnology is still in its infancy and as such is still very much embedded in the scientific world. Although this is a speculation, research would appear to be closer to fundamental science than to applied science in this very narrow field. The results for nanotechnology in general do not yield consistent results and we are currently in the process of distinguishing the various subfields that compose nanotechnology to disentangle the 'closeness-to-market' effect in the fundamental versus applied science.

Regarding the position of individual scientists in the co-publication network, our results show a strong and positive influence of centrality (both degree centrality and betweenness centrality) and cliquishness. More central individuals publish more papers, whether he had more collaborators in the past (degree centrality) or is in a better intermediary position (betweenness centrality). For a start, more central researchers have a wider network of collaborators. With the tendency in recent years to dramatically increase the number of co-authors on scientific articles, this can contribute to increasing the number of articles of each individual. In addition, past individual cliquishness also accounts for an increase in productivity.

As for the debate on the 'big 5' universities in Canada, of which two are located in Quebec (McGill University and University of Montreal), we cannot say that our results support their claim, certainly not in terms of scientific production. The omitted dummy variable is for the University of Montreal (including the affiliated engineering school Ecole Polytechnique of Montreal), to which the results should be compared. Being located at McGill University or Laval University (in Quebec city), contribute to increasing a scientists' productivity by more than 8% compared with the University of Montreal. These results are however weakly significant and not robust throughout the 6 models presented. Further investigation is therefore required regarding this debate. We can say that there is no evidence so far that researchers from the two 'best' universities in Quebec publish 'more' than their colleagues in other universities in the province. The 'publish or perish game' is the same for all universities and researchers conform to it. The argument put forward in Wells' [56] article by the five top university presidents is that they should be allowed to "pursue world-class scientific research and train the most capable graduate students".

Work that is more cited is one way of verifying whether they already pursue more world-class research. We have already shown from the elementary statistics that McGill University generally produces work that is more cited than that of other universities (see Fig. 3). But does that mean that more money is required to produce such world-class research? Is it sufficient to pour money into a research group to make it produce highly cited world-class research? Our results (presented in Table 2) would tend to say no; neither the number of grants, nor the average amount of grants received per year averaged over three or five years yield very significant results. We have tested the introduction into the model of the interactive dummy variables $d_{91\text{-}93}$ to take into account the loophole in the law, as in Table 1, but neither contract variables are significant. These results are presented in Table 5 in the annex to this paper. The number of grants received over a period of three years is positive but weakly significant. In addition, the number and amount of contracts obtained by researchers do not influence the number of citations either. Hence money does not seem to matter. Since a large part of the grants are devoted to student stipends and other research assistant salaries, and that these salaries are generally fixed by the grant awarding bodies, there is not much difference across universities in terms of salaries and stipends. As a consequence, it is not surprising that the amount of research money at the disposal of researchers does not seem to have an influence on citations.

What seems to matter is the intrinsic characteristic of researchers. Our model tries to take this into account using four variables. The first one refers to the number of papers a scientist publishes. Intuitively, the more papers a scientist produces, the more citations he is likely to get. The second and third measures relate to the past position of a researcher in the co-publication network: degree centrality and betweenness centrality. The fourth measure is also a network measure: cliquishness.

Let us first examine the number of papers published. When estimating linear regressions using panel data, one has to determine whether a fixed-effect or a random effect model is more appropriate. In our case, the vast majority of researchers do not change university in the course of their career. As a consequence, each university dummy variable is nearly constant within each group (scientist). A fixed-effect model is therefore not appropriate as the time-constant variables are correlated with the dummy variables used for the fixed-effects. Random-effects do not have this problem. Having said that, once still has to verify that the random effect is the most appropriate using the test devised by Breusch and Pagan [9] and the Hausman [36] specification test. While we had not problems with rejecting the Breusch-Pagan test, the Hausman specification test proved trickier. We had to use the old trick of replacing the variables which exhibit the largest differences between the fixed- and random-effects models by their within and between effects. In other words, replacing the troublesome variables by their mean across time (within effect) for each subject and the deviance from that mean (between effect).

For the number of papers, the variable $nbpaper_t$ is replaced by $averpaper_t$ and $nbpaper_t$ - $averpaper_t$. In a sense, the within effect takes into consideration the intrinsic quality of a researcher. Both variables are positive and significant in the regressions 7 to 12. The results for both measures of degree centrality (for three- and five-year networks) show counterintuitive results. While its average value ($averdegcentind3_{t-1}$ and $averdegcentind5_{t-1}$) yields positive and significant values, implying that a more central individual in the past is more likely to get more citations in the future, the coefficient of its deviation is negative and significant. Once a researcher has reached some kind of notoriety and has collaborated with a greater number of colleagues, his number of citations does not augment with the introduction of one more collaborator. We would have expected that the migration from the periphery of the network to its center, hence some kind of recognition of quality, would have a positive effect on future citations. Hence there appears to be a limit with the number of people with whom a person can collaborate in terms of its effect on recognition by peers. This result is partly in agreement with Sandström *et al.* [49] who show that researchers are more likely to cite authors with whom they are personally acquainted, hence that social networks matter. The same is true for betweenness centrality. Cliquishness does not however produce robust results across the models as it is only significant for models (9) and (12). Its effect is nevertheless positive on the number of citations.

Table 2 – Random-effects regression results – natural log of the number of citations five-years after publication

	(7)	(8)	(9)	(10)	(11)	(12)
$averpaper_t$	0.1873***	0.1963***	0.2677***	0.1882***	0.1971***	0.2687***
	(0.0234)	(0.0228)	(0.0230)	(0.0235)	(0.0229)	(0.0230)
$nbpaper_t$ - $averpaper_t$	0.2056***	0.2064***	0.2050***	0.2058***	0.2067***	0.2053***
	(0.0081)	(0.0081)	(0.0081)	(0.0081)	(0.0081)	(0.0081)
$nbgrant3_{t-2}$	0.0038*	0.0039*	0.0039*			
	(0.0021)	(0.0021)	(0.0022)			
$nbgrant5_{t-2}$				0.0021	0.0021	0.0022
				(0.0015)	(0.0015)	(0.0015)
$ln(avergrant3_{t-2})$	-0.0031	-0.0036	-0.0049			
	(0.0065)	(0.0065)	(0.0065)			
$ln(avergrant5_{t-2})$				-0.0056	-0.0061	-0.0071
				(0.0068)	(0.0068)	(0.0069)
$nbcont3_{t-1}$	-0.0020	-0.0021	-0.0021	-0.0019	-0.0020	-0.0020
	(0.0037)	(0.0037)	(0.0037)	(0.0037)	(0.0037)	(0.0037)
$ln(avercont3_{t-1})$	-0.0033	-0.0031	-0.0029	-0.0029	-0.0027	-0.0025
	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)	(0.0040)
10^4 x $averdegcentind3_{t-1}$	0.0452***			0.0452***		
	(0.0089)			(0.0089)		
10^4 x ($degcentind3_{t-1}$ - $averdegcentind3_{t-1}$	-0.0087*			-0.0086*		
	(0.0046)			(0.0046)		
10^4 x $averdegcentind5_{t-1}$		0.0362***			0.0363***	
		(0.0076)			(0.0076)	
10^4 x ($degcentind5_{t-1}$ – $averdegcentind5_{t-1}$		-0.0127**			-0.0126**	
		(0.0051)			(0.0051)	
10^4 x $averbetcentind3_{t-1}$			0.0017			0.0016
			(0.0029)			(0.0029)
10^4 x ($betcentind3_{t-1}$ - $averbetcentind3_{t-1}$			-0.0023*			-0.0023*
			(0.0012)			(0.0012)
$ln(10^3$ x $cliquind3_{t-2})$	0.0227	0.0255	0.0404**	0.0235	0.0263	0.0412***
	(0.0195)	(0.0196)	(0.0185)	(0.0195)	(0.0196)	(0.0185)
dULaval	-0.0467	-0.0466	-0.0674	-0.0455	-0.0455	-0.0661
	(0.0626)	(0.0627)	(0.0640)	(0.0627)	(0.0628)	(0.0640)
dMcGill	0.2218***	0.2198***	0.2170***	0.2227***	0.2207***	0.2181***
	(0.0602)	(0.0604)	(0.0617)	(0.0604)	(0.0605)	(0.0618)
dConcordia	0.1508	0.1698	0.1838	0.1462	0.1650	0.1801
	(0.1505)	(0.1507)	(0.1558)	(0.1508)	(0.1509)	(0.1560)
dSherbrookeBishop	-0.1389	-0.1390	-0.1486	-0.1369	-0.1370	-0.1465
	(0.0891)	(0.0893)	(0.0910)	(0.0893)	(0.0894)	(0.0911)
dUQuebec	-0.1966***	-0.1962***	-0.2087***	-0.1954***	-0.1950***	-0.2073***
	(0.0756)	(0.0758)	(0.0771)	(0.0757)	(0.0759)	(0.0771)
$d_{1985-1995}$	-0.3196***	-0.3201***	-0.3028***	-0.3196***	-0.3200***	-0.3022***
	(0.0457)	(0.0457)	(0.0459)	(0.0460)	(0.0460)	(0.0463)
constant	2.5880***	2.5830***	2.5795***	2.6122***	2.6071***	2.6003***
	(0.0943)	(0.0948)	(0.0967)	(0.0959)	(0.0965)	(0.0985)
σ_u	0.4815	0.4843	0.5066	0.4833	0.4859	0.5079
σ_e	0.7890	0.7887	0.7889	0.7890	0.7886	0.7888
ρ	0.2713	0.2738	0.2920	0.2729	0.2751	0.2931
n	3400	3400	3400	3402	3402	3402
n_{groups}	748	748	748	748	748	748
average nb years	4.5	4.5	4.5	4.5	4.5	4.5

	(7)	(8)	(9)	(10)	(11)	(12)
max nb years	16	16	16	16	16	16
R^2 within	0.1970	0.1977	0.1967	0.1970	0.1977	0.1967
R^2 between	0.3722	0.3693	0.3420	0.3721	0.3694	0.3420
R^2 overall	0.3337	0.3331	0.3289	0.3329	0.3323	0.3280
υ_i~Gaussian Wald $\chi^2(15)$	1165.78	1162.95	1113.28	1163.94	1161.39	1112.17
corr(υ_i,X)	0	0	0	0	0	0

Notes: ***, **, * show significance at the 1%, 5% and 10% levels respectively.
Standard errors are presented in parentheses

Going beyond the individual quality of scientists, the five university dummy variables for any the local environment of the individual researchers. The omitted dummy variable is for the University of Montreal. As a consequence, all things being equal, McGill university scientists receives more citations than University of Montreal. In contrast, universities from the University of Quebec network receive less citations than University of Montreal. Although our results clearly identify McGill as world-class (positive and significant effect on the number of citations), we cannot distinguish the University of Montreal from the other universities with the exception of the universities from the University of Quebec network which yields a negative and significant result. Despite the fact that the coefficients are not significant for these other universities, their sign raise an interesting question: Is there a language or culture bias as suggested by Carpenter and Narin [12] and Menou [41]? Indeed, the other French speaking university from Montreal, University Condordia, also yields a positive albeit non-significant value. Our research cannot investigate this claim properly, but it is certainly an avenue of research worth pursuing.

VI. DISCUSSION AND CONCLUSION

At the beginning of this paper, we set out to investigate whether the funding of research as well as the organisation (read collaboration or co-authorship) of research has an impact on the output from this research. A second goal of this research was to contribute to the on-going debate in Canada about the ‘big 5’ claiming that they should concentrate on graduate teaching and world-class research, leaving undergraduate teaching to other universities.

To the first question, the answer is overwhelmingly ‘yes there is an impact’, but there are subtleties. While more research funds undoubtedly lead to more scientific articles, the relationship with citations is inexistent. The same is true for the number of grants as opposed to the total amount of funds obtained. When we turn to contracts, which are generally associated with more applied research, we do not find a negative impact on the scientific production, quite the opposite. More numerous contracts increase the number of articles in a non negligible way. The articles resulting from this research however probably do not lead to world-class research as there is not significant effect from either the number or the amount of contracts received on the number of citations obtained. The effect would have been more decisive if the coefficient had been negative and significant. We suspect that the type of contract might play a role in discerning which ones lead to more recognised research. While our data does not permit this type of analysis at present, we are currently investigating patent-paper-pairs and papers co-authored with industry to try to identify a difference among the papers that stem from research contracts.

Since the amount of research funds at the disposal of researchers does not yield a convincing story, the intrinsic quality of researchers must play the most fundamental role. This latent variable, a scientist' quality, cannot be directly measured, but a number of proxies were used in our analysis. If one agrees that in a field like nanobiotechnology where innovation increasingly requires multidisciplinary teams, innovating alone is no longer possible, then the most 'important' scientists would occupy the most central positions within the co-authorship networks. Hence degree centrality and betweenness centrality can act as proxies for researcher' quality in our impact regressions. Both measures have an impact on scientific productivity (the number of articles) and on the quality of this research (the number of citations).

So what does this tell us? The best universities have a tremendous attracting power for the best scientists, if only because they also recruit the best students. These students are not better paid whether they enrol in a top university or in another institution, so money does not seem to matter to produce world-class research. In addition, because with more funds, more research students can be recruited, this has a direct incidence on the number of articles published, but not on the quality of this research. Now regarding our contribution to the Canadian debate. While McGill University certainly stands out, our assessment of University of Montreal in the field of nanobiotechnology does not single it out as a world-class university. This is not to say that in other fields, the University of Montreal does not offer a top performance.

There is a number of limitations to our research to which we aim to remedy in the future. First, we have examined a rather narrow field, nanobiotechnology. In order to fully support the claims of two of the big 5 universities in Quebec, we would have to assess all the disciplines in which both universities specialise. This is not the goal of our research.

A second limitation concerns the mobility of scientists. Once a scientist moves out of the province, he disappears from our funding radar. We can partially measure the amount of federal funding received by these researchers in the rest of Canada, but contracts and provincial grants are not available, which obviously would lead to a biased picture of the impact of publicly funded research. Scientists from the rest of Canada would appear to produce more with less funds! A potential solution to that would be to gain access to the curriculum vitae of these researchers and hope that they are complete. We will investigate with the three granting agencies in Canada whether this is possible.

A third limitation of our study is the data. Although we have tried to extract as much of the articles of the researchers identified in the intersection between the nanotechnology and the biotechnology fields, it is possible that some escaped our net. For instance, Scopus does not include all scientific journals and as more journals are added every year, the coverage changes constantly. As a consequence, the citation measures suffer in accuracy especially towards the beginning of the sample.

In addition, what our model cannot measure however is the impact of graduate students on the production of a research team. Furthermore, we have not yet been able to reconstitute research groups that transcend universities apart from co-publications. The data available to us via SIRU does include a title of the project funded by the contract or the grant. Unfortunately since this information comes from numerous sources (i.e. from each university), there is no consistency in the reporting. The title of a particular project thus differs across universities. We are investigating data mining techniques that would allow to reconcile these data and hence reconstitute, so to speak, the original teams. Adding to those the students that are funded through scholarships would allow us to measure the funding received by particular laboratories or research teams. This is however a very complex data matching exercises which require careful screening. We have only scratched the surface, there remains a great deal of work to be done.

APPENDIX

Table 3 – Descriptive Statistics

Variables	Obs	Mean	Std Dev	Min	Max
nbcit5	5837	50.937	76.324	1.000	1458.000
$nbpaper_t$	5837	2.530	2.230	0.000	24.000
$nbgrant3_{t-2}$	5837	12.153	10.410	1.000	111.000
$avergrant3_{t-2}$	5837	229233.300	662241.400	0.000	15900000.000
$nbgrant5_{t-2}$	5837	18.905	16.009	1.000	162.000
$avergrant5_{t-2}$	5837	201779.500	491197.600	71.010	9722040.000
$nbcont3_{t-1}$	5837	2.302	6.009	0.000	136.000
$avercont3_{t-1}$	5837	55396.680	404118.300	0.000	11600000.000
10^4 x $averbetcentind3_{t-1}$	5806	7.922	17.022	0.000	268.432
10^3 x $cliquind3_{t-2}$	5806	27.072	29.289	0.000	341.589
10^4 x $averdegcentind3_{t-1}$	5806	5.370	5.375	0.000	52.588
10^4 x $averdegcentind5_{t-1}$	5807	6.095	5.853	0.000	52.612

Table 4 – Correlation Matrix

Variables		1	2	3	4	5	6	7	8	9	10	11	12
$ln(nbcit5_t)$	**1**	1.000											
$nbpaper_t$	**2**	0.501	1.000										
$nbgrant3_{t-2}$	**3**	0.129	0.183	1.000									
$ln(avergrant3_{t-2})$	**4**	0.080	0.113	0.547	1.000								
$nbgrant5_{t-2}$	**5**	0.119	0.192	0.962	0.539	1.000							
$ln(avergrant5_{t-2})$	**6**	0.084	0.125	0.548	0.961	0.562	1.000						
$nbcont3_{t-1}$	**7**	0.011	0.080	0.280	0.144	0.308	0.161	1.000					
$ln(avercont3_{t-1})$	**8**	0.023	0.136	0.352	0.246	0.377	0.264	0.544	1.000				
10^4 x $averbetcentind3_{t-1}$	**9**	0.248	0.463	0.105	0.078	0.107	0.088	0.008	0.056	1.000			
10^3 x $cliquind3_{t-2}$	**10**	0.148	0.194	0.067	0.038	0.066	0.048	0.012	0.061	0.299	1.000		
10^4 x $averdegcentind3_{t-1}$	**11**	0.317	0.516	0.171	0.118	0.176	0.131	0.038	0.112	0.812	0.553	1.000	
10^4 x $averdegcentind5_{t-1}$	**12**	0.329	0.524	0.182	0.130	0.195	0.146	0.044	0.123	0.794	0.503	0.949	1.000

Table 5 – Random-effects regression results – natural log of the number of citations five-years after publication (with interactive dummies on contracts for 1991-1993)

	(7’)	(8’)	(9’)	(10’)	(11’)	(12’)
$averpaper_t$	0.1875***	0.1965***	0.2675***	0.1883***	0.1973***	0.2686***
	(0.0234)	(0.0228)	(0.0230)	(0.0235)	(0.0229)	(0.0230)
$nbpaper_t$ - $averpaper_t$	0.2059***	0.2066***	0.2054***	0.2061***	0.2069***	0.2057***
	(0.0081)	(0.0081)	(0.0081)	(0.0081)	(0.0081)	(0.0081)
$nbgrant3_{t-2}$	0.0038*	0.0039*	0.0039*			
	(0.0021)	(0.0021)	(0.0022)			
$nbgrant5_{t-2}$				0.0021	0.0022	0.0022
				(0.0015)	(0.0015)	(0.0015)
$ln(avergrant3_{t-2})$	-0.0031	-0.0036	-0.0049			
	(0.0065)	(0.0065)	(0.0065)			
$ln(avergrant5_{t-2})$				-0.0056	-0.0061	-0.0072
				(0.0068)	(0.0068)	(0.0069)
$nbcont3_{t-1}$	-0.0019	-0.0019	-0.0020	-0.0018	-0.0018	-0.0019
	(0.0037)	(0.0038)	(0.0038)	(0.0038)	(0.0038)	(0.0038)
$ln(avercont3_{t-1})$	-0.0025	-0.0025	-0.0018	-0.0021	-0.0021	-0.0014
	(0.0042)	(0.0042)	(0.0043)	(0.0042)	(0.0043)	(0.0043)
$nbcont3_{t-1}$ x d_{9193}	-0.0065	-0.0064	-0.0062	-0.0064	-0.0064	-0.0061
	(0.0141)	(0.0141)	(0.0141)	(0.0141)	(0.0141)	(0.0141)
$ln(avercont3_{t-1})$ x d_{9193}	-0.0037	-0.0023	-0.0052	-0.0037	-0.0023	-0.0052
	(0.0102)	(0.0102)	(0.0102)	(0.0102)	(0.0102)	(0.0102)
10^4 x $averdegcentind3_{t-1}$	0.0450***			0.0450***		
	(0.0089)			(0.0089)		
10^4 x ($degcentind3_{t-1}$ - $averdegcentind3_{t-1}$	-0.0085*			-0.0084*		
	(0.0047)			(0.0047)		
10^4 x $averdegcentind5_{t-1}$		0.0361***			0.0362***	
		(0.0076)			(0.0076)	
10^4 x ($degcentind5_{t-1}$ – $averdegcentind5_{t-1}$		-0.0124**			-0.0122**	
		(0.0051)			(0.0051)	
10^4 x $averbetcentind3_{t-1}$			0.0016			0.0016
			(0.0029)			(0.0029)
10^4 x ($betcentind3_{t-1}$ - $averbetcentind3_{t-1}$			-0.0023*			-0.0023*
			(0.0012)			(0.0012)
$ln(10^3$ x $cliquind3_{t-2})$	0.0232	0.0257	0.0410**	0.0240	0.0265	0.0418***
	(0.0195)	(0.0196)	(0.0185)	(0.0195)	(0.0196)	(0.0185)
dULaval	-0.0472	-0.0471	-0.0679	-0.0461	-0.0460	-0.0665
	(0.0626)	(0.0627)	(0.0640)	(0.0627)	(0.0628)	(0.0640)
dMcGill	0.2221***	0.2199***	0.2175***	0.2230***	0.2208***	0.2186***
	(0.0603)	(0.0604)	(0.0617)	(0.0604)	(0.0605)	(0.0618)
dConcordia	0.1528	0.1712	0.1863	0.1481	0.1664	0.1825
	(0.1505)	(0.1507)	(0.1558)	(0.1508)	(0.1510)	(0.1561)
dSherbrookeBishop	-0.1382	-0.1385	-0.1478	-0.1362	-0.1365	-0.1457
	(0.0891)	(0.0893)	(0.0910)	(0.0893)	(0.0894)	(0.0911)
dUQuebec	-0.1981***	-0.1975***	-0.2102***	-0.1969***	-0.1964***	-0.2088***
	(0.0757)	(0.0758)	(0.0771)	(0.0757)	(0.0759)	(0.0772)
$d_{1985-1995}$	-0.2963***	-0.3019***	-0.2745***	-0.2965***	-0.3020***	-0.2741***
	(0.0548)	(0.0549)	(0.0551)	(0.0552)	(0.0552)	(0.0554)
constant	2.5830***	2.5797***	2.5730***	2.6075***	2.6040***	2.5941***
	(0.0945)	(0.0950)	(0.0970)	(0.0961)	(0.0966)	(0.0987)
σ_u	0.4813	0.4841	0.5064	0.4832	0.4857	0.5077
σ_e	0.7892	0.7889	0.7891	0.7892	0.7889	0.7890
ρ	0.2711	0.2735	0.2917	0.2727	0.2749	0.2928

	(7')	(8')	(9')	(10')	(11')	(12')
n	3400	3400	3400	3402	3402	3402
n_{groups}	748	748	748	748	748	748
average nb years	4.5	4.5	4.5	4.5	4.5	4.5
max nb years	16	16	16	16	16	16
R^2 *within*	0.1971	0.1978	0.1968	0.1971	0.1977	0.1968
R^2 *between*	0.3722	0.3694	0.3422	0.3722	0.3695	0.3423
R^2 *overall*	0.3343	0.3336	0.3296	0.3334	0.3328	0.3287
υ_i~*Gaussian Wald* $\chi^2(17)$	1166.4	1163.29	1114.25	1164.54	1161.7	1113.12
$corr(\upsilon_i,X)$	0	0	0	0	0	0

Notes: ***, **, * show significance at the 1%, 5% and 10% levels respectively.
Standard errors are presented in parentheses

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