On Decreasing Returns to Scale in Research Funding

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Abstract

In most countries, basic research is supported through governmental research councils that select, after peer review, the individuals or teams what will receive funding. Unfortunately, the number of grants these research councils can allocate is not infinite, and many researchers (45% in Quebec) are not able to obtain any funding. A small minority of those who do get funded account for the majority of the available funds. However, it is unknown whether or not this is an optimal way of distributing available funds. The purpose of this study is to measure the relation between the amount of funds given to 14,103 individual Quebec's researchers over a fifteen year period (1998-2012) and the total outcome of their research in terms of output and impact from 2000 to 2012. Our results show that both in terms of the quantity of papers produced and of their scientific impact, the concentration of research funding in the hands of a so-called 'elite' of researchers generally produces diminishing returns.

Conference Topic

Science policy and research assessment

Introduction

In most countries, basic research is supported through governmental research councils that select, after peer review, the individuals or teams that will receive funding. Unfortunately, the number of grants these research councils can allocate is not infinite. For example 20% to 45% of Quebec's researchers, depending on the discipline, had no external funding between 1999 and 2006 (Larivière et al., 2010). National scientific agencies, including the National Science Foundation (NSF – United States) and Natural Science and Engineering Research Council (NSERC – Canada), also tend to give fewer grants of a higher value, which leads to high rejection rates (Joós, 2012; NSERC, 2012; NSF, 2013). In Canada, 10% of the researchers funded by the Social Sciences and Humanities Research Council (SSHRC) accumulate 80% of available funds, 10% of those funded by the Canadian Institutes of Health Research (CIHR) obtain 50% of the funds, and 10% of those funded by the NSERC accumulate 57% of the funds.[1] The situation is similar in Quebec where we combine funding from the national

[1] Data compiled by the Observatoire des Sciences et Technologies (OST) using results of competition for each of the councils, and the *Almanac of Post-Secondary Education in Canada, of the Canadian Association of University Teachers*.

and provincial agencies: 20% of the researchers getting 80% of the funds in social sciences and humanities (SSH), 50% of the funds in health, and 57% of the funds in natural sciences and engineering (NSE) (Larivière et al., 2010). With a few researchers receiving most of the funds available and many not receiving any, it seems legitimate to ask whether this concentration of funds leads to better collective gains than funding policies that promote a more even distribution of funding. The aim of this study is to provide a partial answer to this question, by linking the amount of funding obtained by Quebec's scientists with their research productivity and impact.

Even though the funding of science theoretically plays a substantial role in scientific discoveries, its relation to outcomes has not been extensively researched. McAllister and Wagner (1981) observed a linear relationship between funding and output at the institution level. A few years later, Moed et al. (1998) found that departments of Flemish universities with the most funding actually had a decrease in publications. Other studies (e.g., Heale et al., 2004 and Nag et al., 2013) investigated the relation between the amount of funding and the research output of individual researchers. They reported that one of the strongest determinants of the number of publications was the amount of funding, although an increase in funds did not yield a proportional increase in the number of articles. Thus, there are decreasing returns to scale. Others have found that productivity is only weakly related to funding (Fortin & Currie, 2013), and that publications do not increase linearly with the amount of funding but rather appears to reach a plateau (Berg 2010). On the whole, while most studies—unsurprisingly—found a positive relationship between inputs and outputs, very few have looked at decreasing returns to scale associated with the concentration of research funding. Nicholson and Ioannidis (2012) found that only a minority (about 40%) of all researchers eligible to NIH funding who published highly cited articles (1000 citations or more) actually received such funding. Previous studies found that funded researchers publish more (Gulbrandsen & Smeby, 2005) and are more cited (Zhao, 2010; Jowkar, 2011; Campbell et al., 2010; van Leeuwen et al., 2012) than those who do not receive any funding.

This study aims to contribute to this debate, by analyzing the research output and impact of all of Quebec's researchers from all disciplines over a period of 15 year. More specifically, it aims at answering two questions: 1) how does the research productivity and scientific impact of individual researchers vary with the amount of funding they receive? 2) Is this variation similar in the three general fields of science that are health, natural sciences and engineering, and social science and humanities?

Methods

Data on funding for all Quebec's academic researchers from 1998 to 2012 were obtained from the Information System on University Research, an administrative database from the Quebec provincial government that covers all funded research in Quebec's universities. Researchers were divided in three broad research disciplines: Social Sciences and Humanities (SSH), Natural Sciences and Engineering (NSE) and Health according to the discipline of their university department. Some were put in two different disciplines (N=169), and those for whom the discipline was not known and not found were excluded (N=263). The number of researchers in each field is shown in table 1. For each researcher, we calculated the total amount of funding received from the three main funding agencies in Quebec (FRQSC [SSH], FRQNT [NSE] and FRQS [health]) and Canada (SSHRC [SSH], NSERC [NSE] and CIHR [Health]). The total funds attributed for each projects were divided equally by the number of researchers on the application, each of them receiving an equal share. Other sources of funding were not taken into account. Publication data for each researcher from 2000 to 2012 were obtained from Thomson Reuters' Web of Science. Since citations take time to accumulate, they were counted up to the end of 2013.

Table 1. Number of Quebec's researchers by field

Field	*Number of researchers*	*Funded*		*Not funded*	
		N	*%*	*N*	*%*
SSH	6,229	3,869	62.1%	2,360	37.9%
NSE	3,244	2,647	81.6%	597	18.4%
Health	4,630	2,666	57.6%	1,964	42.4%
Total	14,103	9,182	65.1%	4,921	34.9%

Similarly to Berg (2010), we divided researchers in bins of equal size (50 researchers per bin), except for the bin regrouping researchers who did not receive any funding (see table 1 for the number of researcher in each field who did not receive funding). For each bin, we calculated the average and median amount of funding received. Then we calculated the average and median of four indicators used to measure the research outcome: the total count of articles, the fractional number of articles, the total number of citations and the average relative citations (ARC).

Results

Figure 1 and Figure 2 provide the mean and median number of papers of researchers, using both full (Figure 1) and fractional counting (Figure 2), as a function of total funding received. For each bin for each discipline and each indicator, the average is higher than the median, implying a skewed distribution of the data. The high values of R^2 in both figures indicate that the number of publications is strongly linked to the amount of funding received by researchers. The best fit line for each domain is a quadratic equation which suggests diminishing returns. For example, the median number of publications of researchers in NSE who received about $5 million is about 72 (and 19 for fractional count), while those who receive $2.5 million published a median number of 47 articles (13 for fractional count). Thus, doubling the funding does not seem to double the output. In Health, the most funded bin received almost three times more funding than the second most funded one, but published only two times more articles. Furthermore, in health, the apex is reached within the data range, which shows that a decline in production could be associated with higher levels of funding. On the whole, the correlation between funding and publications appears to be strong in all fields with values of R^2 higher than 0.91, but for each domain and calculation method, a rapid growth in the number of publications is observed for smaller amounts received and is followed by a slower growth as funding increases. However, this effect is less apparent for the total number of publications in SSH.

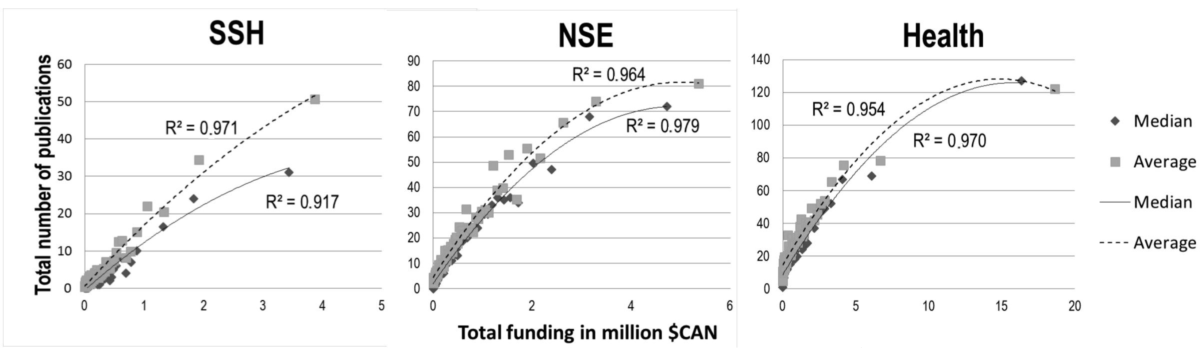

Figure 1. Full number of publications as a function of the amount of funding received.

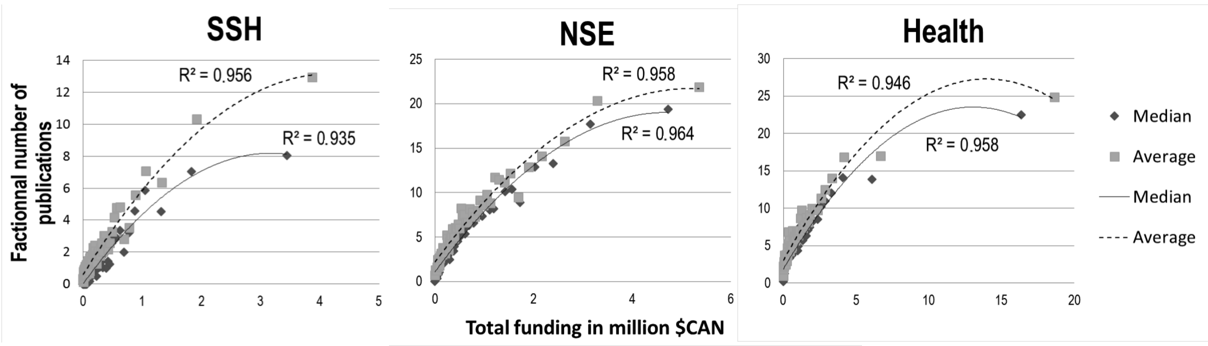

Figure 2. Fractional number of publications as a function of the amount of funding received.

Figure 3 shows the relationship between raw citations and funding received; the best-fit line is also a quadratic equation suggesting decreasing returns to scale in scientific impact. Similar to publications, the relation between the average of relative citations and the amount of funding (Figure 4) is weaker than for the previous indicators, with R^2 between 0.4 and 0.9. The nature of the relation is also different, the best-fit line being a power function, except for the median in SSH and the average in NSE, which are quadratic function. The power function indicates decreasing returns: the average relative of citations keeps increasing when increasing the total of funding, but not proportionally. For both impact indicators, we observe a trend similar to that observed for the number of publications. While the impact of papers published increase rapidly for funding of less than approximately $2 million in NSE and $5 million in health, the total number citations increase at a much slower pace once this threshold is met. Here, SSH are the exception, with the total number of citation seemingly increasing more rapidly for highly funded researchers. For field-normalized citations, the impact remains almost the same for all fields after a threshold of approximately $1 million is met.

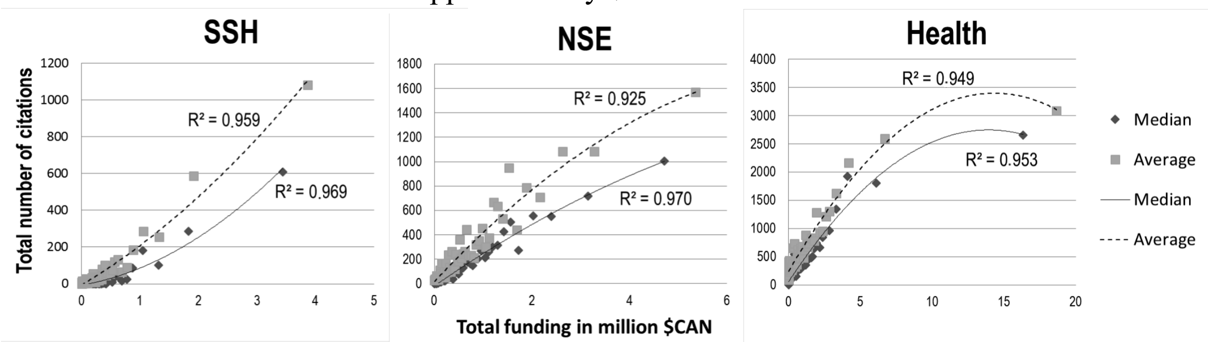

Figure 3. Total number of citations as a function of the amount of funding received.

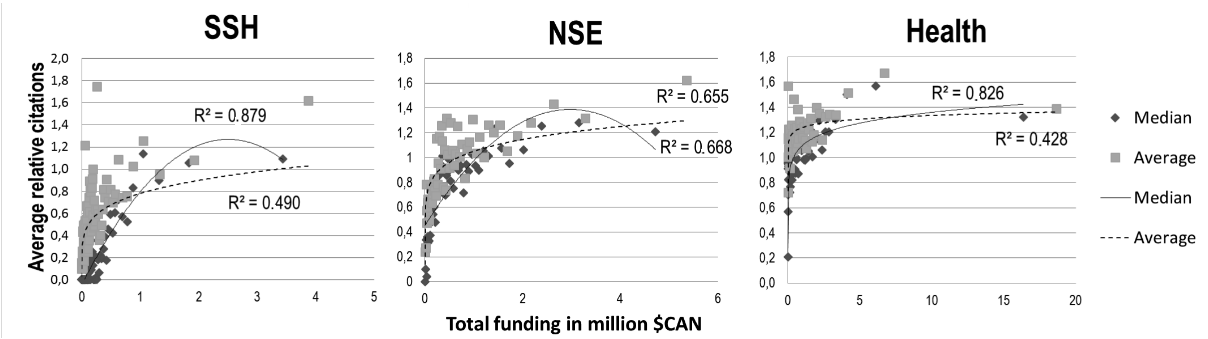

Figure 4. Average relative citations as a function of the amount of funding received

Discussion and conclusion

Based on our observations, funding is strongly linked to productivity and impact of individual researchers, but there are decreasing returns to scale for all of the indicators measured, except for the total citation count in SSH. This suggests that, even though more funding does in general lead to a higher number of publications, giving bigger grants to fewer individuals may not be optimal. If maximum output is the objective, then giving smaller grants to more researchers seems to be a better policy. In terms of scientific impact, the quickly reached plateau indicates that increasing funding has a very small impact on relative citations. Again, if the goal of research funding is to generate research that has a greater impact, giving grants to more researchers seems to be a better decision.

According to our results, SSH seem to be an exception, showing very little decreasing returns to scale. However, this could be explained by the fact that some research specialties in SSH (e.g., psychology and geography) have publication practices that are similar to those in NSE or Health. A closer look at the data shows that some researchers in psychology and geography tend to be both more funded – since they are often funded by the health and natural sciences funding agencies respectively – and more prolific than those in other field. Twenty-three (23) of the 50 most funded researchers and 33 of the 50 most prolific researchers are in those two fields, while they were 10 out of 50 in a randomly selected bin of researchers with less funding. Thus, the lower decrease in return of research funding in SSH could potentially be explained by an overrepresentation psychology and geography researchers in the highly funded bins, and their underrepresentation in less funded ones.

One of the many potential explanations for these decreasing returns is the high cost of equipment and infrastructures. Some research projects may simply not be possible without these initial investments, which do not necessarily lead to more output. Furthermore, while receiving funding does provide researchers with the means to carry on their research projects, it does not guarantee that they will succeed at achieving publishable results. Research grants are sometimes used as a performance indicator, which encourages researchers to apply for more grants (Hornbostel, 2001) that they might not necessarily need. This could lead to an inefficient use of the funds received (Sousa, 2008). Another explanation could be that researchers receiving larger grants may not participate directly on all the work funded with those grants (Boyack & Jordan 2011)

Some limitations of this study should be acknowledged. We did not control for other factors that can have an impact on a researcher's productivity (e.g., team size, academic age or gender), so further research may want to take into account such factors, as well as sources of funding other than government grants. Also, some of the potential outcome of funding and research cannot be measured with bibliometric indicators (e.g., the number of students trained and social outcomes). The funding received is sometimes linked to a particular project, and further research could aim at comparing outcomes of funded projects specifically. Another limit might be the lower coverage of SSH publications in the Web of Science, since researchers in SSH tend to publish in local journals or to publish books. Finally, as discussed above, the division of researchers in three broad disciplines might be problematic, especially for SSH. A more precise clustering of researchers based on research topic could provide better results and a clearer understanding of the phenomenon of decreasing returns of research funding.

In sum, both in terms of the quantity of papers produced and of their scientific impact, the concentration of research funding in the hands of a so-called 'elite' of researchers generally produces diminishing returns. In a context where financial resources devoted to research are declining in constant dollars, it is important to ask whether the way funding is allocated is optimal. Our numbers show that it is not the case: a more egalitarian distribution of funds would yield greater collective gains. It should be understood that the main determinant of scientific production is not so much the money invested, but, rather the number of researchers' at work and, by funding a greater number of researchers, we increase the overall research productivity. Research policies that concentrate financial resources also seem to forget that there is a certain degree of serendipity associated with scientific discoveries, and by funding the work of many researchers as possible, we increase the likelihood that some of them make major discoveries.

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