

Sex differences in research funding, productivity and impact: an analysis of Québec university professors

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Abstract

Using the entire population of professors at universities in the province of Quebec (Canada), this paper analyzes the relationship between sex and research funding, publication rates, and scientific impact. Since age is an important factor in research and the population pyramids of men and women are different, the role of age is also analyzed. The paper shows that, after they have passed the age of about 38, women receive, on average, less funding for research than men, are generally less productive in terms of publications, and are at a slight disadvantage in terms of the scientific impact (measured by citations) of their publications. Various explanations for these differences are suggested, such as the more restricted collaboration networks of women, motherhood and the accompanying division of labour, women's rank within the hierarchy of the scientific community and access to resources as well as their choice of research topics and level of specialization.

Keywords

Sex; research funding; research productivity; research impact; collaboration; age; universities; Québec; Canada

Introduction

When the first woman to receive a Masters' degree from McGill University, Harriet Brooks, got married in London in 1907, a brilliant research career came to an end. Since women of that era were often forced to leave their jobs after marriage, Brooks was resigned – though not without a battle with the administration of Barnard College at Columbia University – to abandoning her position as a young professor (Rayner-Canham and Rayner-Canham, 1992; Rossiter, 1982). Before getting married, this nuclear physics specialist had been mentored by none other than Ernest Rutherford and Marie Curie, with whom she worked on – but never completed – her doctoral studies.

Although women in Western societies in general, and within the scientific community in particular, have made great strides since Harriet Brooks, several studies have demonstrated systematic differences between the sexes within scientific and technological fields, and within the research community as a whole, both in the province of Québec (Conseil de la science et de la technologie du Québec [CST], 1986; Heap and Sissons, 2010; Lasvergna-Grémy, 1984) and elsewhere (Cole, 1987; Xie and Shauman, 2003; Zuckerman, Cole and Bruer, 1991). Despite the fact that there is an increasingly proportion of female professors in Québec (Conférence des recteurs et des principaux des universités du Québec [CREPUQ], 2010), there is no sense of whether or not this progress in terms of workforce composition has led to a greater presence in the research sphere. Based on the entire set of Québec professors, the present study analyzes the correlations between sex and research funding, publication rate, as well as scientific impact. Since age is an important factor in research (Feist, 2006; Gingras et al., 2008; Simonton, 2004) and the population pyramids of men and women are different (see figure 1B), the data presented here are also broken down according to the researchers' ages. Furthermore, we analyze trends in

each of the three broad fields: health sciences, natural sciences and engineering (NSE) and social sciences and humanities (SSH).

After surveying the main published studies pertaining to the place of women in the scientific community, we present the sources of data and methods employed, followed by our main results. The discussion presents the various interpretations that may help elucidate the trends observed while the conclusion reflects on the possibility of future changes in the basic values that underlies the present hierarchy of disciplines which favors male contributions to science.

Literature review

A survey of the vast majority of studies completed since the 1990s clearly shows a gap of approximately 30% in research productivity between men and women, as measured through the number of publications. In other words, women publish between 70% and 80% as many articles as men (Fox 2005; Prpic, 2002; Schiebinger, 2003; Xie and Shauman 1998, 2003). This is a marked improvement over previous disparities: Zuckerman's review (1991) found that women published, on average, 40% to 50% fewer articles than men. Results for the cases of the United States (Etzkowitz, Kemelgor and Uzzi, 2000; Fox, 2005; Leahey, 2007; Xie and Shauman, 2003), Canada (Nakhaie, 2002) and elsewhere in the world (Bordons et al., 2003; Gonzalez-Brambila and Veloso, 2007; Mauleón & Bordons, 2006; Prpic, 2002) have been similar, considering both science as a whole and individual scientific disciplines.

Results from the existing literature are more nuanced when it comes to comparing the scientific impact of men's and women's work. Some studies have indicated similar levels of impact of men and women's publications (Bordons et al. 2003; Gonzalez-Brambila and Veloso 2007; Long and Fox, 1995; Mauléon and Bordons 2006; Zuckerman, 1991 citing Cole and Zuckerman, 1984)

even, occasionally, a higher impact of women in certain scientific disciplines (Long, 1992; Borrego et al. 2010). Other studies have shown that women's patents had a higher impact than men's (Bunker Whittington and Smith-Doerr 2005). These studies give credence to the often invoked hypothesis that women focus more on research quality, while men focus on the quantity of publications (Sonnert and Holton 1995). Another set of studies showed that articles written by women obtain, on average, fewer citations than those of their male counterparts (Peñas and Willett, 2006; Turner and Mairesse, 2005) or take longer to reach their maximum number of citations (Ward, Gast and Grant, 1992). Bordons et al. (2003) were able to estimate the scientific impact of research (via the impact factor of journals) for three groups of Spanish researchers, finding similar impacts between men's and women's work in two of the three disciplines examined.

In terms of research funding, Stack (2004) showed that a smaller proportion of women receive financial support (mainly through research grants): 37.7% compared with 43.3% for men. Similarly, Feldt (1986) found that male adjunct professors from the University of Michigan received more money for their laboratories and had access to better installations than their female colleagues. Similar results were obtained in an analysis of the status of women faculty at MIT (MIT, 1999). Based on National Science Foundation (NSF) and National Institutes of Health (NIH) data, Fox (1991, p. 202, quoting Zuckerman 1987) concluded that both sexes receive a number of grants proportional to the number of proposals submitted, which was thus posited as the source of the observed disparity.

Sources and methods

Authors' relevant socio-demographic information can only rarely be found directly from scientific articles. Therefore, in order to compile bibliometric data on scientific production and break it down according to age and sex, one must begin with a list of researchers containing the required information. The list of university¹ and clinical researchers used in this study (N=13,636) was obtained from the *Ministère du développement économique, de l'innovation et de l'exportation du Québec* (MDEIE) and the three provincial granting councils². In addition to their dates of birth and sex, each individual in the list was ascribed a broad field of research (health, NSE or SSH), based on their respective departments and the nature of their research.

Data on research funding came from the *Système d'information sur la recherche universitaire* (SIRU maintained by the *Ministère de l'éducation du loisir et du sport du Québec* (MELS)). The SIRU database includes grants awarded by the various granting councils as well as scientists' research contracts, and was compiled for the 2000-2008 period. Research projects involving many universities were attributed to each institution based on its fraction of professors involved, instead of simply assigning each project to the principal investigator (PI). We have also excluded grants from the *Canadian Foundation for Innovation* (CFI) and its provincial counterparts, since the majority of these grants are for infrastructure and are not directly linked to the research

¹ There are 15 universities in Québec: Bishop's University, Concordia University, Université Laval, Université McGill, Université de Montréal, Université de Sherbrooke, Université du Québec à Montréal, Université du Québec à Trois-Rivières, Université du Québec à Chicoutimi, Université du Québec à Rimouski, Université du Québec en Outaouais, Université du Québec en Abitibi-Témiscamingue, Institut national de la recherche scientifique, École nationale d'administration publique, École de technologie supérieure.

² *Fonds de la recherche en santé du Québec* (FRSQ), *Fonds québécois de recherche sur la société et la culture* (FQRSC) and *Fonds québécois de la recherche sur la nature et les technologies* (FQRNT).

project itself³. Finally, in order to keep only professors who are involved in research, only those having obtained some type of funding, irrespective of its source – government, industry, etc – at least once during the 2000-2008 period (N=9,074) were considered. When limiting the analysis to professors whose age could be determined the size of our sample reduced to 7,064.

Bibliometric data on scientific publications were found from the Thomson Reuters Web of Science (WoS), which annually indexes the articles published in approximately 11,000 journals across all disciplines within health, NSE and SSH. Although this database indexes several different types of documents (journal articles, letters to the editor, reviews, etc.), only articles and review articles are considered here, since they are generally accepted as the main instruments for communicating original research (Carpenter and Narin, 1980; Moed, 1996). The WoS does not, however, cover all work published by researchers from Québec (or anywhere else, for that matter), since some are disseminated through non-indexed national journals, or other types of documents such as conference proceedings, grey literature and books. WoS limitations affect our examination of SSH in particular: the objects of SSH research tend to be more ‘local’ in nature and a larger proportion of their publications thus tend to be in local or national journals. These limitations are amplified in the case of non-English-speaking countries (Archambault et al., 2006). In addition, SSH researchers publish more books and book chapters than their colleagues in health or NSE (Larivière et al., 2006), which translates into a lower coverage of their scientific production within WoS.

³ Similarly, we also sought to limit the impact of other types of infrastructure grants not explicitly indicated as such (unlike those from the CFI) and assigned to a single researcher, but which, in fact benefit an entire research group. We have therefore excluded researchers whose funding, for a given year, was greater than three times the standard deviation of the distribution of all funding received in a year.

Attributing articles to a given university researcher from our list is a more complex process, since there is no unique code associated with each individual within the WoS. Therefore, given the large number of duplicate names, in order to correctly attribute articles to researchers, each paper with the ‘correct’ surname and initial had to be manually and individually validated⁴. After this validation process, at least one article was successfully attributed to 8,485 Quebec researchers, a number which reduces to 6,231 when filtered according the availability of age data (as discussed above).

As shown in Figure 1A, the percentage of women in each field differs considerably: 36% in SSH, 30% in health and only 14% in NSE. In fact, the larger proportion of women in the social sciences is directly linked to the strong growth of these disciplines in the 1960s, attracting more women than men (Gingras and Warren, 2007). In addition, health and SSH disciplines are often characterized by a greater focus on ‘care’, which is known to play a role in attracting women to certain career paths (Cockburn, 1988; Collin, 1986; Witz, 1992). The age distribution of men and women also differs considerably: while women account for about 40% of professors under 35 years of age, they represent less than 20% of those over 60 years of age. Women are also, on average, three years younger than men (CREPUQ, 2010), and this tendency is visible in all three groups of disciplines under study here. More specifically, the average birth year of men is 1954 compared to 1957 for women in health sciences, 1954 compared to 1957 in SSH, and is 1955 compared to 1960 in NSE. On the whole, we see here that the age difference between men and women is quite similar in SSH and health sciences (women are about 3 years younger), but is greater in NSE where women are younger by about 5 years.

⁴ For more details on how articles were attributed to Québec researchers, see Larivière (2010).

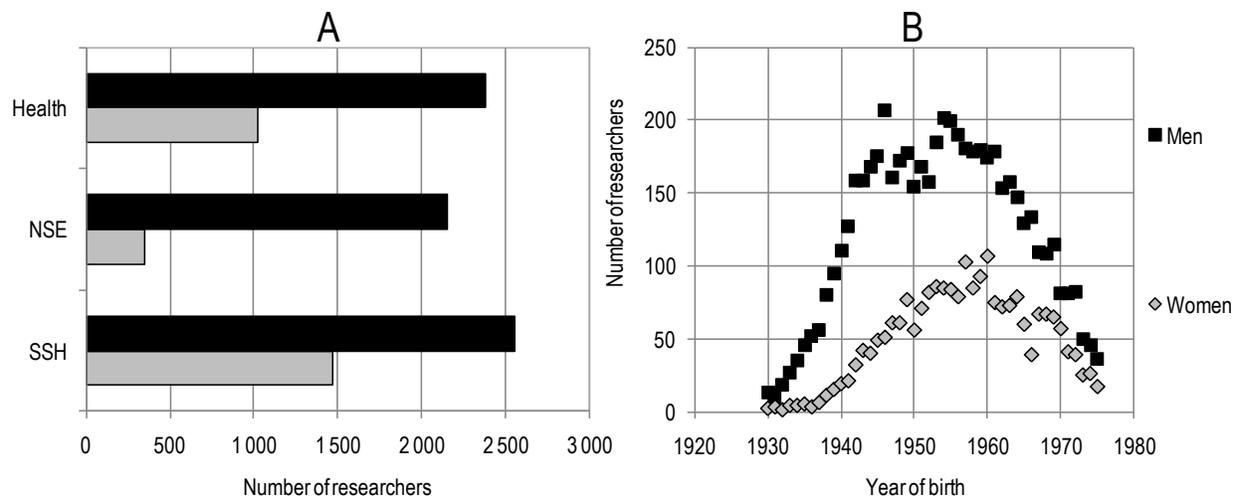


Figure 1. A) The number of researchers, broken down according to gender and field; B) The distribution of researchers according to gender and date of birth.

Since data on funding and publications are only available for the 2000-2008 period and not for the entire research career of individuals, data on the age of researchers are compiled using a cross-sectional method. Contrary to longitudinal studies which would study a single age group across time, a cross-sectional study compares – for a short period of time – measurements obtained for different age groups. Hence, our results do not show the evolution of the career of individual researchers over time but, rather, how different age groups compare with each other at a specific point in time. For each grant received or article published in a given year, we subtract the researcher’s birth year to obtain his or her age. Thus, a paper published in 2005 by a researcher born in 1955 would be attributed an ‘age’ of 50, while a publication in 2006 by the same researcher would have an ‘age’ of 51. The aggregation of data therefore means that values corresponding to the age of 50 would include funding or publications occurring in 2000 for researchers born in 1950, as well as those occurring in 2001 for researchers born in 1951, and so on. In order to present averages based on a sufficient amount of data ($N > 50$ in each of the three

fields), data are only compiled for professors aged between 30 and 70 and the curves shown use a three-year running average.

Results

Research funding Data on research funding shows that, in each of the three fields, women receive less funding than their male colleagues. In health, men receive more than twice as much as women (\$261,000 vs. \$113,000 over the period studied), while the difference is smaller, but still significant in NSE (\$143,000 vs. \$100,000) and SSH (\$56,000 vs. \$41,000). It is nevertheless noteworthy that, when we restrict our scope to funding from the six granting councils⁵, the differences are much smaller (though still significant): \$109,000 vs. \$66,000 in health, \$61,000 vs. \$54,000 in NSE and \$24,000 vs. \$22,000 in SSH. This decrease indicates that men have more varied sources of funding, beyond the traditional avenues that are the granting councils. The very slim gap in SSH funding from granting councils likely reflects the fact that these disciplines have had a greater female presence over a longer period of time, and women thus have a greater chance in receiving funding through peer review than from a process based on other considerations – e.g., research contracts – and likely relying on extra-academic networks, in many cases. It is also possible that this disparity in funding simply reflects differences in the number of applications for funding, as suggested by Fox (1991, citing Zuckerman, 1987). Fox linked this difference in the levels of funding to a marginalization of women within the scientific community and to their smaller social networks therein, which in turn affects their chances of informally receiving information regarding funding processes or, more generally, on funding possibilities. In other words, these differences are not necessarily due

⁵ Three Canadian and three Quebec ones: The Social Sciences and Humanities Research Council (SSHRC), the Natural Sciences and Engineering Research Council (NSERC), the Canadian Institutes of Health Research (CIHR), the FRSQ, the FQRSC and the FQRNT.

to different rates of success in competing for funds, even though recently compiled American data suggests that success rates remain a factor (NIH, 2010).

In order to take into account the difference in the age pyramids of men and women, Figure 2 shows, for each field, how funding – overall and from the six granting councils – changes according to the age of researchers. One immediately notices that, in each field, funding obtained by women plateaus more quickly than that obtained by men, especially in the case of health⁶. Indeed, while funding received is, on average, the same until a person's late thirties, for female researchers it increases very slowly – perhaps even remaining constant – while men's funding increases until their fifties. Research funding obtained by men then decreases at a similar rhythm as during its increase, reaching the same levels as for women towards the end of their careers (in their early sixties). In NSE and SSH, funding trends are similar, even though the difference between men and women is less important. Again, when only considering the six granting councils, funding levels for the two sexes are similar, just as is the case for average values of grants (discussed above). As a whole, Figure 1 demonstrates that, at certain ages, female researchers are funded at the same levels as their male counterparts, while at other points in their careers, they receive significantly less funding than men. This clearly shows that age is not the only factor to be considered in understanding the difference in funding levels between the two sexes. We will return to this point in the discussion, below.

⁶ This figure also shows a result which, while not directly linked to the present study, is quite interesting: funding from the six granting councils plateaus earlier than funding as a whole. This difference is especially large in SSH, where, for men, funding from the six councils reaches a maximum in their early forties, while overall funding peaks in their early fifties. This suggests that while granting councils rely solely on expert peer review to make funding decisions, other kinds of funding tend to depend more on seniority, reputation and social networks.

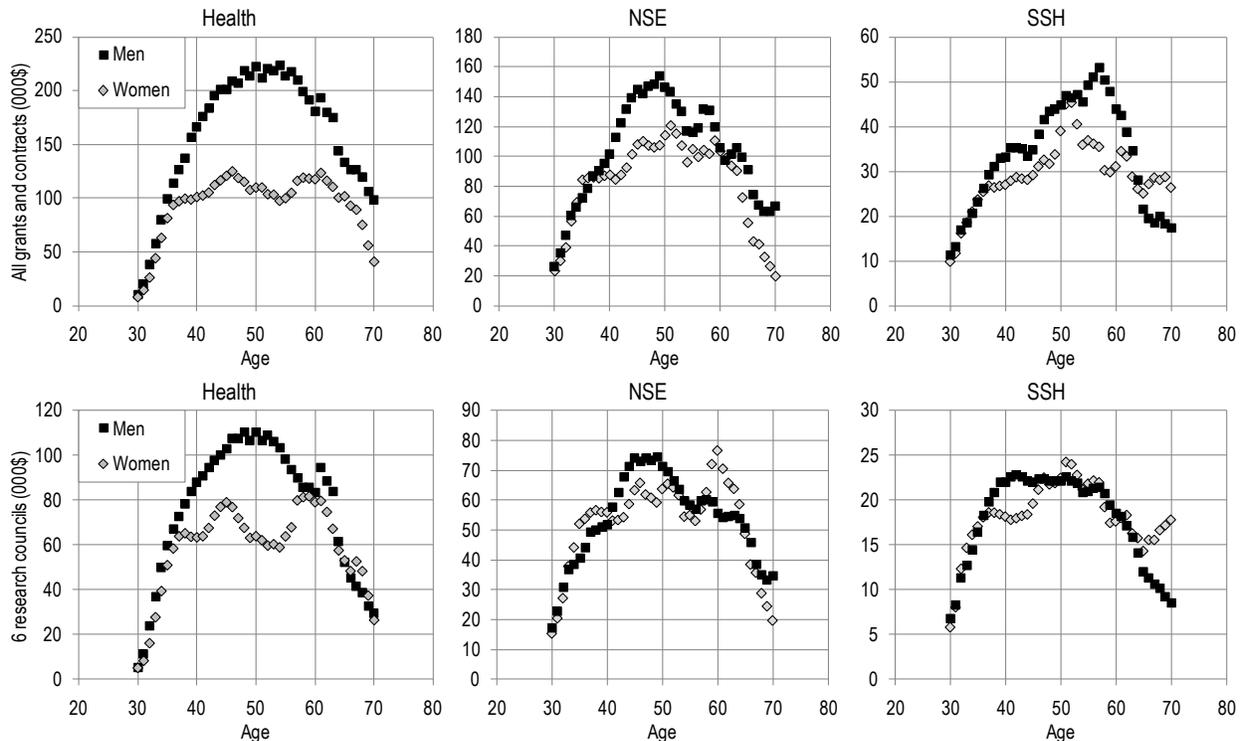


Figure 2. Research funds obtained (all sources and limited to the six federal and provincial granting councils), according to age and field. Three-year moving averages.

Research productivity

As mentioned in the introduction to this paper, several studies have shown a difference in the number of articles published by men and women. Unsurprisingly, data from Québec point in the same direction. While male researchers in the field of health published, on average, 19 articles during the period examined here (2000-2008), their female counterparts published approximately 12 articles. In NSE, there is a 20% difference (19 vs. 13 articles) and in SSH a 40% difference (3.2 vs. 2.3). Of course, the productivity of researchers in SSH is lower than that of researchers in NSE and health, as they often publish books (Larivière et al., 2006) or publish in local journals that are not necessarily indexed in the WoS (Archambault et al., 2006). Figure 3 shows scientific productivity according to the age of researchers and based on three indicators: the total number of articles published, the number of articles published as the first author and the number

of articles published as the last author. While the number of first authored articles provides an indication of the number of projects for which men and women are the main contributors, instances where a given researcher is the last author indicate projects performed under their supervision or within their research team, given that directors of a research group tend to be last in the list (Biagioli, 2003; Pontille, 2004)⁷.

In health and NSE, we note that the total number of articles published follows a trend similar to the funding received and, early in their career, men and women publish comparable numbers of articles. However, as was the case for grants, the slope of the curves changes drastically when the authors reach their mid-thirties, the number of men's articles then increasing much more quickly than those of women. Similar or stronger trends (especially in the field of health) are found when we restrict ourselves to researchers as last authors which, in general, implies positions as research group leaders. Though the trends are not as differentiated in the case of SSH, it is once again clear that women, at most points in their career, publish less than men. While in this case the order of authors' names is not as significant as it is in the other two fields, it nonetheless tends to reflect the rank of relative contribution to the work. It should also be noted that, in SSH, articles usually have only one author and only very rarely have more than two.

When we restrict ourselves to researchers as first authors, different trends are observed. First, within each field, the number of articles decreases fairly regularly as researchers get older, as previously observed for science as a whole by Gingras et al. (2008). Also, we observe only

⁷ It goes without saying that this practice is more common in health and NSE, as well as in those fields within SSH where research teams are more common, such as psychology. On the other hand, in SSH disciplines where collaboration is less frequent, the order of authors is generally according to their degree of contribution. Notable exceptions to these rules is high-energy and particle physics, where names are listed in alphabetical order (Birnholtz, 2006; Galison, 2003).

minimal differences in the number of articles published by men and women within each field. Scientific production by women is thus similar to that of men, when considering only articles for which they are the primary contributors. The proportion of articles where the researcher is a first author also varies as a function of sex and age. In the case of health, this proportion decreases rapidly at the beginning of a career, and then remains stable for both men and women in their early forties. For women, the subsequent drop is much less steep than for men, reaching a minimum at 15% just before their fifties. The proportion then oscillates between 15% and 20% until the end of their career. NSE trends are similar, though there is no noticeable difference between men and women, whereas such a difference persists in SSH.

Overall, these data suggest that the difference in productivity between the sexes is not only due to the different shape of their respective age pyramids, but also due to the fact that, when women become senior researchers they are less likely to direct research teams, a situation also reflected in their global scientific production. This is likely linked to the fact that women receive less research funding than men, though the data can only establish the correlation and not a causal relationship between these two findings.

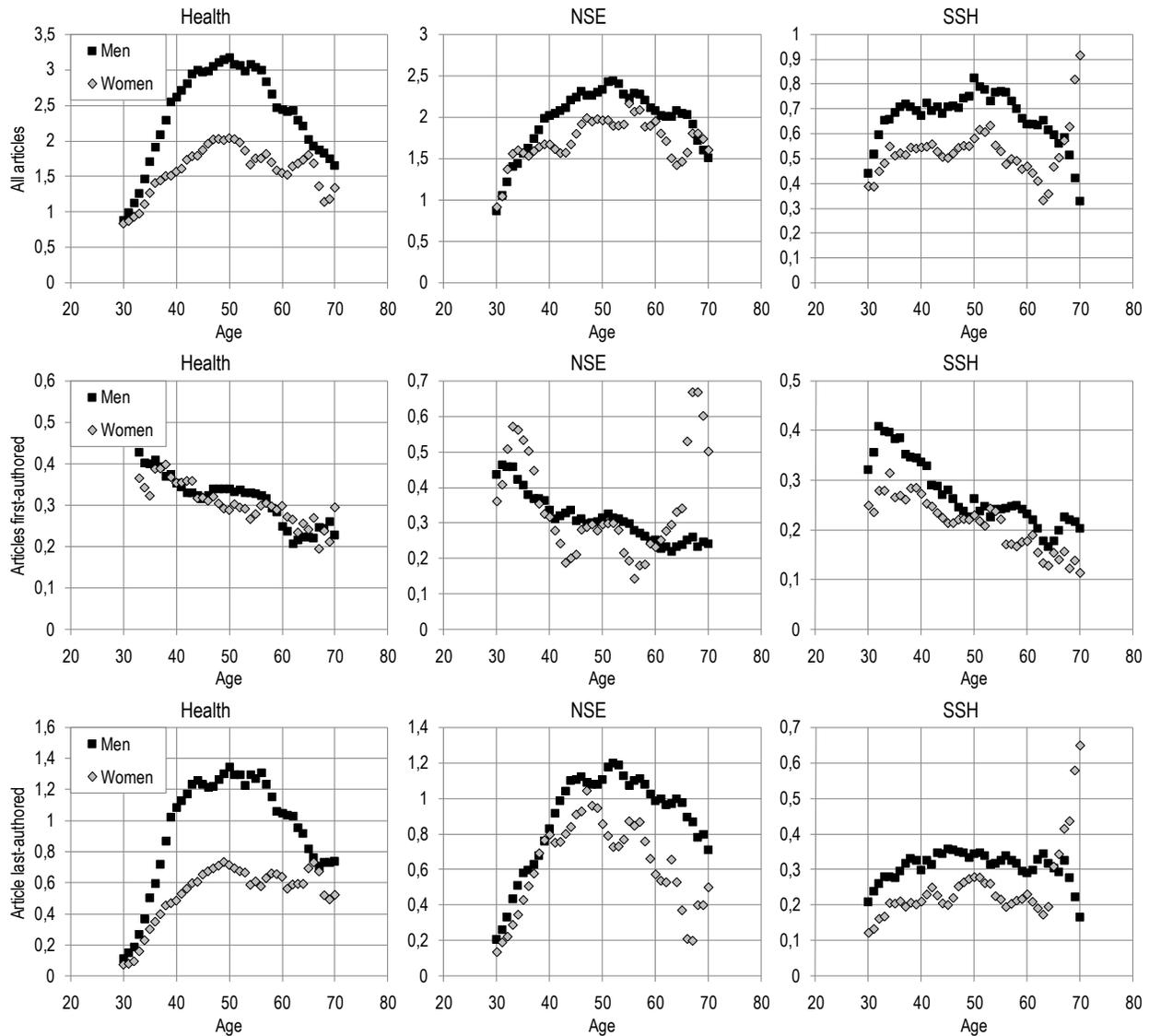


Figure 3. Average number of articles published (all articles, as the first author only, as the last author only), according to gender age and discipline. Three-year moving average.

Another factor contributing to explain the observed productivity differences in Figure 3 is collaboration. Men have, over the period studied, more distinct collaborators than women in health (80 vs. 52.9) and in NSE (44.5 vs.38.9). The reverse is true in SSH though the difference is small (10.5 vs. 9.3). Similarly, just as has been previously shown by Larivière (2007) using a smaller dataset, we find that men’s articles are more likely be produced as part of an international collaboration (Figure 4A) than women’s articles. In the field of health, 39% of

men's articles were written with partners from outside Canada, compared with 30% of women's articles. There is a 5% difference (39% versus 34%) in NSE and an 8% difference (31% vs. 23%) in SSH. We can therefore conclude that men, on average, have a wider international scientific network than women. Conversely, as shown in Figure 4B, a larger proportion of women's articles arise from collaboration with other Québec researchers. The sex difference here is even more pronounced than for international collaboration: 69% vs. 48% in health, 46% vs. 30% in NSE, 47% vs. 36% in SSH. This larger proportion of local collaboration could be linked to a greater dependence on other researchers or research teams in Québec. Overall, these numbers show that the collaboration network of women scientists is more local in nature while that of their male colleagues is more international.

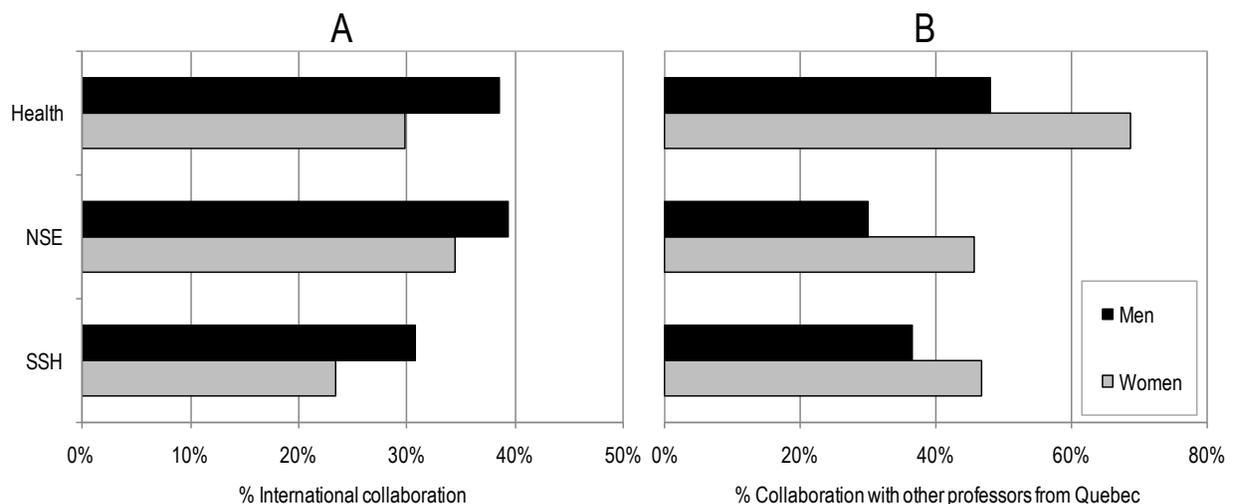


Figure 4. Collaboration rate of Québec articles according to sex and field. A) International collaboration, B) Collaboration with other researchers from Québec.

Research impact

Two indicators are generally used in bibliometrics in order to gauge the scientific impact of articles: the impact factor and the number of citations. The former is based on the average impact of articles published in a given journal – measuring both the ‘reputation’ of the journal and the

expected impact of articles. The latter, on the other hand, is based on the impact of each of the individual articles by counting the number of times they were cited by other articles. In order to take into account different citation practices across disciplines (within the field of health, for instance, biomedical articles are generally cited more frequently than clinical articles), values obtained for each article are normalized by the average of citations received by articles within a given specialty. Thus, the average relative impact factor (ARIF) or the average of relative citations (ARC) are higher than the world average when their value is greater than one, and vice versa. In addition, the impact factor of journals is recalculated in order to eliminate asymmetry between the numerator and denominator⁸.

Figure 5 shows the scientific impact of researchers' articles according to sex, averaging over all ages. In the field of health, men tend to both publish in more prestigious journals (ARIF values of 1.27 vs. 1.17) and have significantly larger ARC values (1.47 vs. 1.23) than their female colleagues. Characterizing trends in NSE is more complex: while women and men publish in journals of comparable reputation (ARIFs of 1.17 and 1.16), women are cited significantly less (1.27 vs. 1.18). Not unlike the results found for Russian articles (Pislyakov and Dyachenko, 2010) and Québec doctoral students (Larivière, 2010), it seems that female NSE researchers from Québec may be victims of the Matthew Effect (Merton, 1968; Rigney, 2010) and, as such, do not fulfill their citation potential as their male colleagues do. They also suffer from a sex-specific affliction, which Rossiter (1993) called the 'Mathilda Effect', whereby women's contributions are systematically undervalued or dismissed. Finally, women's SSH articles are published in journals of comparable impact (ARIFs of 1.08 vs. 1.06) and receive comparable

⁸ For more details, see Archambault and Larivière (2009).

citations (ARCs of 1.13 vs. 1.11). To reiterate, the sex differences in scientific impact vary across fields; they are minimal in SSH while extremely significant in health.

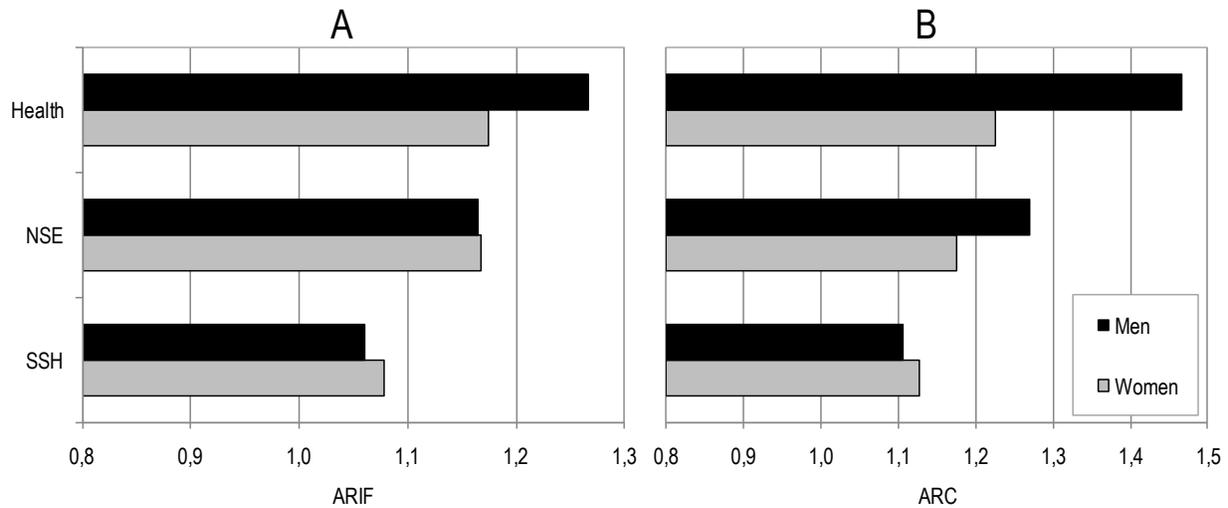


Figure 5. Scientific impact of Québec researchers' articles according to field and sex: A) The average relative impact factor (ARIF), and B) The average of relative citations (ARC).

Discussion

Several factors, many of which have been invoked above, can explain the systematic differences between men and women in terms of scientific funding, productivity and impact. We have highlighted several connections – of varying strength, depending on the discipline – relating to the fact that men are older, and thus have more seniority within the hierarchy of the scientific community. Results have also indicated that women tend to have more restricted collaboration networks: women have less distinct collaborators than men, and collaborate more than men with other colleagues from Québec. Furthermore, it seems that men, throughout their careers, remain more productive than women. However, it is also apparent that the number of articles arising from projects for which men and women conducted the majority of work (first author) was the same overall across all ages and fields of study.

It remains difficult to demonstrate strict causal links in a system that contains feedback mechanisms (publications lead to grants, which lead to further publications), but it is evident that the lower levels of funding for female researchers is probably one of the main factors explaining their lower productivity, at least towards the end of their career if not throughout. Funding can be viewed as the reward for past research, but also as a resource allowing future research to take place. Female researchers in Québec are thus caught in a negative feedback loop: they receive less funding, on average, than their male colleagues, which in turn reduces the amount of future scientific research, thus reducing the amount of future funding and number of publications. That being said, funding is not the only source of the differences observed: when comparing the share of funding for female researchers and their share of publications for each age, we find that men remain more productive given equivalent levels of funding. In other words, at each age and for each discipline, men account for a larger proportion of publications than their proportion of the funding received, while for women, it is the opposite. Although this might be caused by genders' different choice of research topics, it nonetheless shows that there are factors other than funding explaining the difference in scientific productivity between sexes. The existing literature on the place of women within the scientific community should provide vital clues for our discussion of results. Specifically, one must appeal to qualitative factors that affect research practices, as well as biological and social constraints that have a direct bearing on male and female researchers.

A first set of factors that arises from the literature is marital status and the presence of children. Indeed, the role of the mother – and the accompanying division of labour – has meant that women bear a greater share of the burden of domestic responsibilities. Naturally, this situation implies less time and effort available for research work, thus making women less productive than

their male colleagues (Etzkowitz, Kemelgor and Uzzi 2000; Rosser, 2004; Sax et al., 2002). Similarly, several authors have underlined the fact that having children has an adverse impact on the productivity of women (Long, 1990; Hunter and Leahey 2010), particularly when the children are under ten years old (Kyvik, 1990; Kyvik and Teigen, 1996; Stack, 2004). Fox (2005) also showed that the composition of the family was a good predictor of women's productivity. Indeed, while women with adult or university-age children were found to be the most productive in Fox's sample (including men's and women's subsamples), women with younger children requiring more care constituted the least productive group. In addition, in an increasingly international scientific community, women with children are generally less mobile (Long and Fox, 1995). This decreased mobility – and therefore smaller breadth of networks, as implied by our data on female researchers from Québec collaborating more often with researchers from the same province – likely explains part of the decreased scientific impact of women within certain fields, since (in general) articles written with international partners tend to have higher citation rates (Glänzel, 2001). The fact that the impact of women is comparable to those of men in SSH – a field where international collaboration is generally much lower – gives further credence to this hypothesis.

Other studies, on the other hand, have shown that the impact of family on women's productivity is minimal (Cole and Zuckerman, 1991) or even, more surprisingly, positive (Barzebat 2006; Bellas and Toutkoushian 1999; Fox and Faver 1985; Stack, 2004), as a result of better time management skills brought about by more experience in dealing with professional and domestic constraints. Whatever the exact nature of the impact of family life on productivity, our data clearly show that a bifurcation in the productivity of both sexes occurs in the mid-thirties. Taking into account a lag of about two years between the writing of an article and its subsequent

publication, the bifurcation occurs probably around 35-36 years. In Québec, according to 2009 preliminary data from the Institut de la Statistique du Québec (2010), the median age at childbearing (regardless of the rank of the child) is between 25 and 29 years for all women, but between 30 and 34 years when they have a university degree. The levelling off of the increase in funding and publications shortly after mid-thirties for women who have become professors is consistent with the above data on child rearing and strongly suggest an effect of family choices by women who, still, generally handle the larger part of family management. A report from MIT (1999) also shows that family and children are potential obstacles to academic success for women, but not necessarily to that of men. Hunter and Leahey (2010), also find complex and distinct relationships between family management – which can predate the birth of the first child by several years – or raising children on the one hand, and productivity and visibility (through numbers of citations) on the other hand, both for men and women.

A second set of factors is linked to rank within the hierarchy of the scientific community and access to resources. Several studies have showed that women were more inclined to work in less research-intensive universities (Sonnert and Holton, 1995; Xie and Shauman, 1998) or, when in more research-intensive institutions, to occupy lower-level positions than their male colleagues (Fox, 1991; Leahey, 2007; Sonnert and Holton, 1995). Similarly, Xie and Shauman (1998) showed that access to graduate students and post-doctoral researchers – the labour force required to do research – as well as to research funding, equipment and available time for doing research (as opposed to teaching and service) were unequally divided among male and female faculty members. Barbezat (2006), Bellas and Toutkoushian (1999), and DesRoches et al. (2010) also showed that women typically devote more time to administrative and teaching activities – at the expense of research – than their male counterparts.

Finally, another interesting hypothesis suggests that women generally specialize less than men, choosing instead to work on a wider variety of research topics throughout their careers. Leahey's studies (2006, 2007) yielded results that support this hypothesis as applied to the fields of linguistics and sociology. According to her, a greater degree of specialization benefits men by leading to a perception of greater professional expertise, thus bestowing greater authority, prestige and influence upon them. This hypothesis is representative of a broader current within the literature that analyzes the unfavourable position of women within science as a result of the 'masculine' nature of dominant scientific practices and content.

Conclusion

This article shows that, on average, women at universities in Québec receive less funding for research than men, are generally less productive in terms of publications, have a more restricted and local network of collaborators, and are at a slight disadvantage in terms of the scientific impact of their publications as measured by citations. The various types of hypotheses that we have just presented are, in our view, the most promising avenues for explaining the systematic differences between male and female researchers in the scientific community. Furthermore, our results confirm several of these hypotheses. Thus, the observed tendency of women to collaborate more with partners from Québec than those from abroad is consistent with the idea that more family responsibilities could reduce the mobility of researchers and their levels of international collaboration. Data on disparities in levels of funding and productivity – in particular the bifurcation between men and women in productivity observed around the age of 38 – suggest reduced access to the necessary resources for a sustained productivity. As well, the marked difference in productivity when considering only papers published as the last author, both in the health sciences and NSE, also imply inequalities in terms of access to the more

prestigious positions within academia or to becoming heads of research groups. Finally, epistemic factors, such as preferences for certain objects of study or for certain work habits, could help explain the disparities in productivity that we observe. In SSH, for instance, where the proportion of female researchers is greater, the scientific impact of their work is not different from that of their male counterparts, even if the productivity gap persists.

We would also like to direct the reader's attention to one last point regarding the observed differences in funding received from sources other than the main granting councils. In the context of an academic community increasingly encouraged to seek funding, new collaborations or new research topics by turning to the private sector, community organizations or other levels of government, the lower performance of women found in our data may indicate structural barriers that are not yet well understood. Within the biomedical sciences, for example, where industry has, for quite some time, played a central role in the production of scientific knowledge, female researchers could find themselves excluded from an extended network (a basic network being essentially academic in nature) of increasing importance in the current context of scientific production. This implies a need for more scholarly work to understand the participation of women in the 'third' (societal, community-based or entrepreneurial) mission of universities, which tends to be increasingly important in comparison to – if not in direct competition with – the fundamental missions of a university: teaching and research.

Finally, it should be recalled that what counts as 'legitimate' or 'important' research is still a function of the dominant agents of a scientific field (Bourdieu, 2004). Given that men still occupy, more often than not, the dominant positions and participate actively in the formulation of research policies, and that many women also internalized these 'dominant' values, it could

happen that even in the current reconfiguration of the tasks assigned to universities, domains that are considered ‘significant’ will remain for a long time those of ‘hard’ and ‘masculine’ science. For example, research on the genome is considered more important than nutrition and dietetics, even though it is scientifically plausible that better eating habits are more likely to lower cancer rates, in the medium term, than personalised genetic manipulations... It is therefore likely that true equality in research will only be achieved when strategic positions, which impose categories of thought and evaluation criteria, are occupied by researchers whose research topics are currently being undervalued. If women’s traditional research topics continue to be directed towards areas that are less prestigious than those chosen by men, and that their importance in academia continues to grow, it is possible that significant changes occur within thirty years. That being said, it is yet to be seen whether the rise of women in positions of power will produce a genuine change in the current hierarchy scientific disciplines and evaluation criteria, or if it will simply lead to the continuation of the same order of things.

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