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Gender Differences in Research Output, Funding and Collaboration

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***Abstract*—**In spite of the global efforts toward gender equality, female researchers are still underrepresented in professional scientific activities. The gender gap is more seen in engineering and math-intensive technological scientific fields thus calling for a specific attention. This paper focuses on the Canadian funded researchers who are active in natural sciences and engineering, and analyses the gender aspects of researchers' performance, their scientific collaboration patterns as well as their share of the federal funding within the period of 2000 to 2010. Our results confirm the existence of gender disparity among the examined Canadian researchers. Although it was observed that male researchers have been performing better in terms of number of publications, the impact of the research was almost the same for both genders. In addition, it was observed that research funding is more biased towards male researchers and they have more control over their scientific community as well.

***Keywords*—**Bibliometrics, collaboration, funding, gender differences, research output.

I. Introduction

DESPITE the continuous scientific accomplishments of women and the global movement toward the gender equity, women scientists are still underrepresented in science and technology. This becomes even worse in math-intensive technology related fields as female researchers are less likely to be seen in computer science and engineering [1]. Forming half of the global workforce, women are also less present in high academic positions[i] and on average have a more limited access to the research resources and receive lower salaries [2]. Although some recent improvements are observed in women's scientific activities involvement e.g. [3], [4], it is still being criticized from various aspects.

Several reasons are mentioned in the literature for the lower productivity of the female researchers which are mainly caused by the women's roles in the society and family. Marriage, age and maternity are some examples of the gender-related factors that can influence the productivity of researchers [5]. However, one should interpret the effect of these gender-related factors with caution. For example, although female researchers are on average producing less publications than their male counterparts [6], [7], it has been observed that mother researchers are more productive than or have at least the same productivity with the non-mother or single female researchers [8].

Number of publications has been widely used in the literature as a measure of scientific output e.g. [9], [10]. In one hand, researchers publish their results in books or journal articles or present them in scientific conferences to preserve priority for their discoveries and raise their scientific reputation. On the other hand, number of publications is one of the influencing factors in securing research funding and getting academic promotions. Several studies performed gender analysis at various levels (*e.g.* countries, scientific disciplines) focusing on the number of publications. Many researchers have found a higher productivity for the male scientists e.g. [11]-[14]. However, there exist some studies that found no difference between the productivity of male and female researchers e.g. [15]-[18]. Hence, no general consensus is found in the literature about the gender role in scientific productivity that could be mainly due to the use of different datasets or different scopes of the projects.

The results become more diverse when it comes to the analysis of the impact of publications. Citation counts and journal impact factor indicators have been mainly used in the literature for assessing the impact of publications. Several studies have found no significant relation between gender and citation patterns e.g. [18]-[21]. However there exist studies that observed lower number of citations for the female authored papers [7], [14] and vice versa [22], [23]. The mixed results are also seen in the studies that focused on the impact factor of the journals in which female and male researchers have published articles, ranging from no difference [18], [24], [25] to higher impact factor for the male researchers e.g. [14] and higher impact factor for the female researchers e.g. [23].

Collaboration is another important aspect of scientific activities that can facilitate researchers' access to pools of knowledge, novel skills and expertise and even new financial resources. Number of authors per paper is one of the main proxies that have been used in the literature for analysing scientific collaboration. The findings of gender analysis of collaboration are also mixed where some studies found no difference among male and female researchers *e.g.* [26] while there are also studies that showed a lower rate of collaboration for the female researchers *e.g.* [27]. The findings are more consistent about research funding where some studies found better access of male researchers to financial support *e.g.* [12], [28], [29] while others observed an equality in relative success rate of acquiring grants *e.g.* [30], [31].

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[i] Also known as "Leaky Pipeline" phenomenon

This study focuses on the Canadian researchers who are active in science and engineering and evaluates the gender role in funding, scientific production as well as collaboration. We perform statistical analysis on the large network of the Canadian funded engineers and scientists to assess the gender role in various scientific activities at the individual level of the researchers during the period of 2000 to 2010. An intelligent computer system was designed and coded to assign the genders automatically. The analysis sheds light on the existence of the gender gap in the Canadian network of researchers active in technological, math-intensive engineering fields. Our basic motivating questions are: Is federal funding distribution gender neutral? Are male researchers on average performing better than their female counterparts? Do female researchers tend to collaborate in more knit groups being in contact with lower number of researchers and partners? The remainder of the paper proceeds as follows: next section presents the data and methodology; the empirical results and interpretations are presented in "Results"; the "Conclusion" section discusses the important findings of the research; and the last section presents the limitations and suggests directions for the future work.

II. Data and Methodology

The data for this research was gathered in different phases. In the first phase, we focused on researchers in natural sciences and engineering in Canada and extracted the funded researchers' data from the Natural Sciences and Engineering Research Council of Canada (NSERC). NSERC is the main federal funding organization in Canada and almost all the Canadian researchers in natural sciences and engineering receive a research grant from NSERC [32]. Moreover, the NSERC funding database is public and freely available.

After collecting the funded researchers' data, Elsevier's Scopus was considered for gathering all the information related to the articles (e.g. co-authors, their affiliations, year of publication, citations) that were published by the funded researchers within the period of 1996 to 2010. We also used SCImago to collect the ranking information of journals in which the articles were published for the period of 1996 to 2010. SCImago was chosen as it provides annual data of the journal rankings that enables us to perform a more accurate analysis since we are considering the impact factor of the journal in the year that an article was published not its impact in the current year. In addition, it is powered by Scopus that makes it more compatible with our articles database.

In the next phase, the co-authorship networks of the funded researchers were constructed for the examined period and several network structure measures were calculated at the individual level of researchers and added to the database. In particular, we used Pajek software to calculate the degree centrality and betweenness centrality of researchers. Degree Centrality is defined based on the number of ties that a node has (degree) in an undirected graph. Hence, researchers with high degree centrality should be more active since they have higher number of ties (links) to other researchers [33]. Degree centrality for node i (dc_i) is defined based on the node's degree ($degree_i$) and then the values are normalized between 0 and 1 to be able to compare centralities:

$$dc_i = \frac{degree_i}{highest\ degree\ in\ the\ network} \quad (1)$$

Betweenness Centrality focuses on the role of intermediary individuals in a network. Betweenness centrality of node k (bc_k) is measured based on the share of times that a node i reaches a node j via the shortest path passing from node k [34]. Hence, the more a node lies on the shortest path between two other nodes in a network, the higher betweenness centrality it has that indicates the higher control of the node over other two non-adjacent nodes [33]. Hence, betweenness centrality of node k (bc_k) is defined as:

$$bc_k = \sum_{i \neq k \neq j} \frac{\sigma_{ij}(k)}{\sigma_{ij}} \quad (2)$$

where σ_{ij} is the total number of shortest paths from node i to j and $\sigma_{ij}(k)$ is the number of shortest paths from node i to node j that contains node k. Finally, a state-of-the-art computer system was implemented able to automatically detect the gender of researchers based on their names, affiliation and country. This system enabled us to detect the gender of the Canadian researchers in natural sciences and engineering with a high accuracy. The detected genders were also added to the database. The final database contains 174,773 records of researchers. Having all the required data integrated in a single database, we applied a bibliometric method to study the gender differences in funding, collaboration patterns and scientific activities of the Canadian researchers working in natural sciences and engineering during the period of 1996 to 2010.

III. Results

A. Research Output

According to Table I, majority of NSERC funded researchers during the examined period were male (almost double, 63.6% vs. 32%). However, comparing the overall productivity of genders reveals that male researchers have published almost 5 times more than their female counterparts. In addition, as it can be seen in Table I, male researchers are again on the top when we look at the highest number of publications for a researcher in a year (Max_{yr}).

TABLE I
Research Population, Descriptive Results

Gender	Distinct Researchers		Publications			
	No.	*%*	*No.*	*%*	*Max_{yr}*	*Mean*
Female	15,244	32%	25,578	17.2%	19	1.68
Male	30,315	63.6%	119,321	80.2%	41	3.94
Unisex	1,521	3.2%	2,820	1.9%	21	1.85
Unknown	595	1.2%	1,035	0.7%	29	1.74
Total	47,675	100%	148,754	100%	41	3.1

To better account for the differences in productivity, we investigated the number of publications in detail. As it can be seen in Fig. 1, the majority of researchers of both genders have published less than 5 papers where the number is almost double for the male scientists. However, the gap becomes wider for the other categories of publications where male researchers are heavily dominating their female counterparts. In addition, as it is shown in Fig. 1 (c), the number of female researchers with more than 40 publications is very limited where still we see a significant number of male scientists in the mentioned categories.

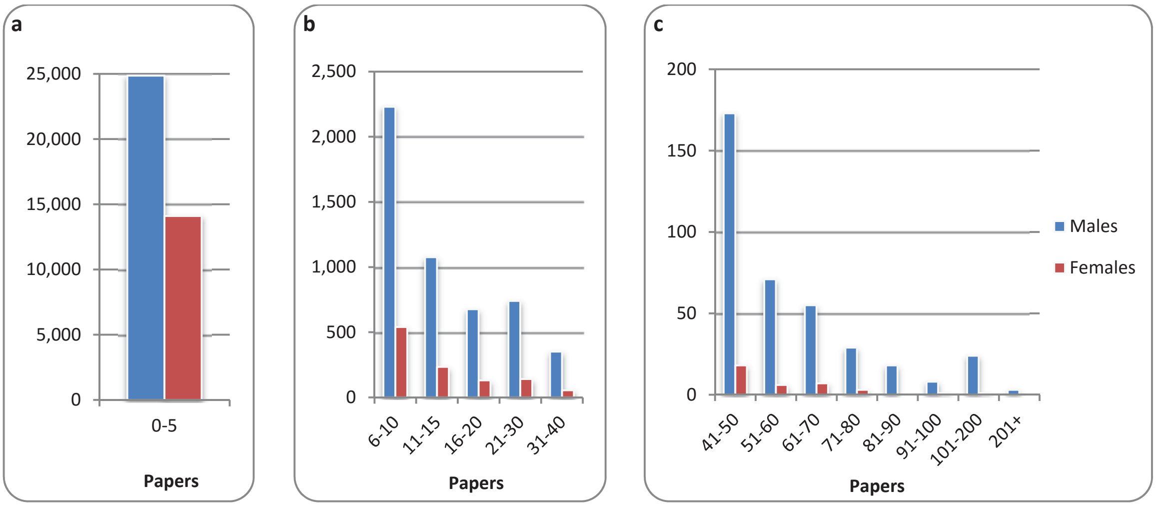

Fig. 1 Researchers distribution based on their gender and productivity: (a) 0-5 papers, (b) 6-40 papers, (c) other categories

To better account for the differences in productivity, we investigated the annual trends of publications as well as the trend of distinct number of funded researchers within the time interval. According to Fig. 2, we see an increasing trend for both genders in scientific output as well as the number of researchers although a slight decrease is seen in the number of publications during the last periods. Interestingly, number of publications is almost 5 times more for male researchers in comparison with their female counterparts in each of the single years. However, the number of male researchers is almost 3 times more than female scientists in each year of the examined time interval. This partially indicates the higher productivity of male researchers in natural sciences and engineering.

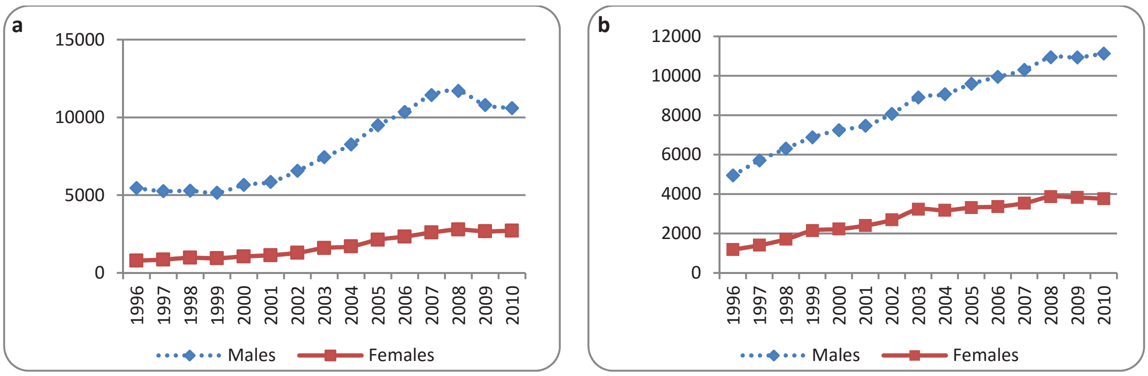

Fig. 2 (a) Number of publications, (b) Number of distinct funded researchers

Apart from the number of publications, the impact of the research output is also important. For this purpose, we took the number of citations as a measure of the research impact and compared the trend of the number citations for males and females. As it can be seen in Fig. 3, interestingly, the trends for both genders are almost the same during the whole time interval. This indicates that in the examined dataset gender does not play an important role in producing publications of high quality. This partially confirms the equal importance of research impact for researchers of both genders in the examined dataset. In addition, it seems that the environmental conditions and influencing factors have equally affected them regardless of the gender.

B. Funding

Fig. 4 shows the overall funding amount allocated to male and female researchers during the whole time interval. As it can be seen there exists a considerable gap between the total amounts allocated to both genders. However, the overall picture cannot be very informative as we also need to consider the number of researchers into the account.

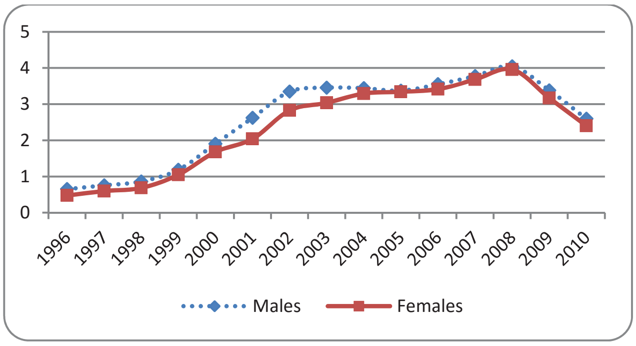

Fig. 3 Number of citations received (same year)

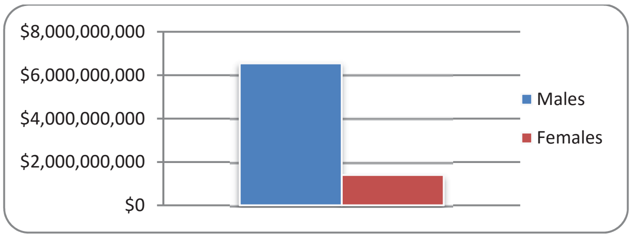

Fig. 4 Total amount of funding

We further investigated the disparity by taking the average amount of funding per researcher for each gender and analysing their trends within the examined time interval. The results are depicted in Fig. 5. From the figure, we can observe three important points: 1) The average amount of funding has been following an increasing trend for both genders over the time interval, 2) The overall trend is almost similar for both genders, and 3) A fixed gap of $15,000 to $20,000 is observed where male researchers on average received a higher amount of funding. From Figs. 2 (b) and 5, we can say that although the number of male researchers were higher than females, on average they have also been receiving more amount of funding.

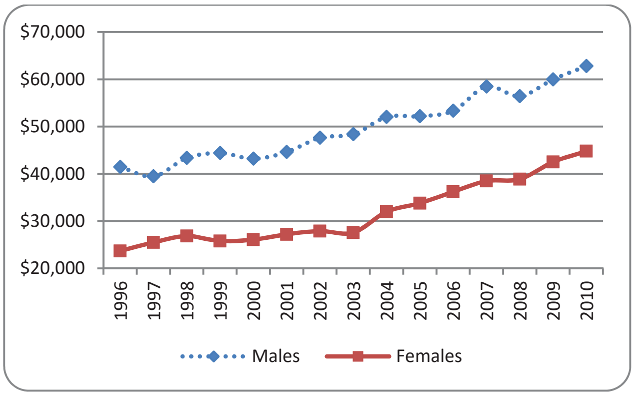

Fig. 5 Average amount of funding

C. Scientific Collaboration

In the last part of the study, we focused on the collaboration patterns and analyzed the gender role. For this purpose, we used a common measure of collaboration (i.e. number of co-authors per paper) along with two social network measure (i.e. degree centrality and betweenness centrality). Fig. 6 shows the trends of average number of co-authors for both genders within the examined time interval. As it can be seen, the trend is almost the same for both genders indicating the overall importance of collaboration in scientific activities regardless of the gender.

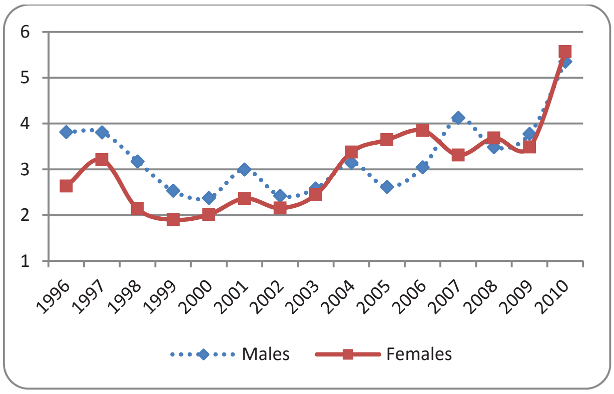

Fig. 6 Average number of co-authors per paper

Degree centrality can be regarded as a measure of the intensity of collaboration as researchers with higher degree centrality have on average collaborated more with other researchers. As it can be seen in Fig. 7, although the degree centrality of male researchers was slightly higher in the beginning periods, the trends have become almost the same after 2004. Moreover, Figs. 6 and 7 are almost similar as we calculated the degree centrality in the co-authorship network of researchers. The drastic increase in the final year of the examined time interval is also worth mentioning.

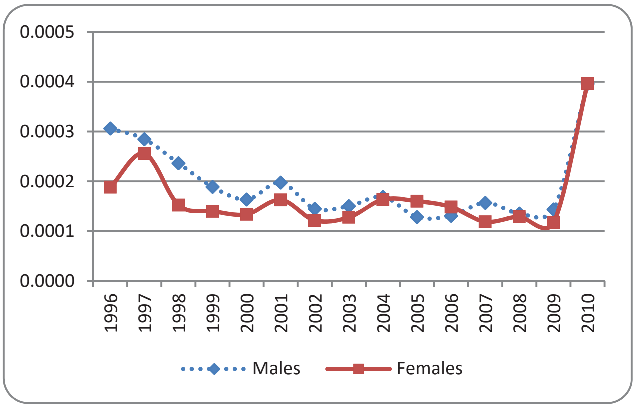

Fig. 7 Average degree centrality

Finally, we checked for the trend of betweenness centrality. Although betweenness centrality was almost the same for both genders before 2000, interestingly we see a drastic increase in the betweenness centrality of male researchers after the mentioned year. However, considering the decreasing trend of male researchers' betweenness centrality in the final two periods, it seems that the betweenness centrality for both genders is again getting close to each other. The higher betweenness centrality of male researchers confirms that they have on average more control on their surrounding community/network in comparison with their female counterparts which might bring them a strategic advantage in securing more funding or getting involved in more research projects.

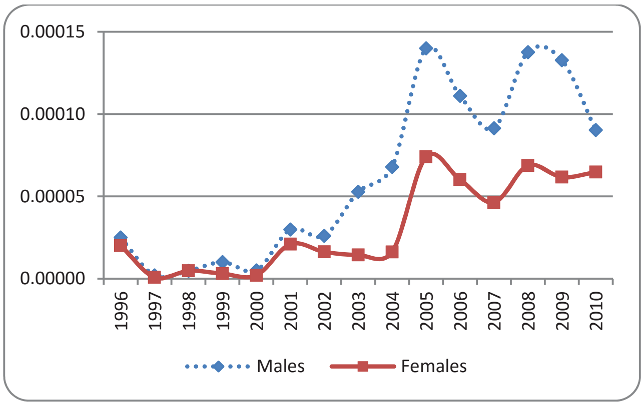

Fig. 8 Average betweenness centrality

IV. Conclusion

In this study, we used a large dataset of Canadian researchers active in natural sciences and engineering and analysed the gender role in scientific activities. Our results confirm the gender disparity in engineering and math-intensive technological research. According to the results, although male researchers show higher performance in term of number of publications, the impact of research in terms of the number of citations is almost equal for both genders. In addition, it was observed that male researchers are receiving more research funding which might help them to be involved in more research projects and to get access to the required research instruments. The funding gap partially explains the gender differences observed in research output. Considering the lower number of female researchers, it is expected that increasing the number of female researchers can help to reduce the gap. Hence, one strategy would be to involve more female researchers in engineering fields. The equal research impact also confirms the value of female researchers in scientific development.

Analyzing the collaboration patterns of researchers revealed that although the average number of co-authors per paper and degree centrality is almost the same for both genders, male researchers have on average higher betweenness centrality. Researchers with high betweenness centrality (gatekeepers) are often critical to scientific collaboration and knowledge diffusion as they can control the flow of information, collaboration and financial resources. Hence, higher betweenness centrality can bring a strategic advantage to male researchers enabling them to have a better control over their surrounding network and community. However, it is not clear that more funding has enabled male researchers to possess more important positions or vice versa.

V. Limitations and Future Work

We were exposed to some limitations in this paper. First, Scopus and other similar databases are English biased, hence, non-English articles are underrepresented [10]. Another inevitable limitation about the data was the spelling errors and missing values. In addition, we used co-authorship networks to analyse the scientific collaboration. Although it is one of the common measures in the literature, we were unable to capture other forms of scientific collaboration as collaboration might not necessarily ends up in the form of a joint article.

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