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Who profits from the Canadian nanotechnology reward system? Implications for gender-responsible innovation

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Abstract:	Gender equality is one of the primary dimensions of responsible research and innovation. Based on bibliometric and survey data of nanotechnology researchers in Canada, this paper analyzes the reward system of science in terms of gender and gender-related institutional cultures. The findings show that gender productivity gaps remain a challenge in the field and that these gaps are reinforced by the fact that the most productive researchers are less likely to collaborate with women. The results also show the amount of extra effort that women must devote to their research to retain their top status in academia, and the extent that their recognition when in top positions is fragile compared to men. This study also confirms the cumulative advantage of creating a gender-inclusive culture that enables women to improve their scientific productivity and impact: such cultures tend to privilege first-author publications over patenting and thus prioritize a type of output where women have had more success. Finally, this paper concludes with policy recommendations for improving the number of women in research and the institutions where they work.

Who profits from the Canadian nanotechnology reward system? Implications for gender-responsible innovation

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Abstract

Gender equality is one of the primary dimensions of responsible research and innovation. Based on bibliometric and survey data of nanotechnology researchers in Canada, this paper analyzes the reward system of science in terms of gender and gender-related institutional cultures. The findings show that gender productivity gaps remain a challenge in the field and that these gaps are reinforced by the fact that the most productive researchers are less likely to collaborate with women. The results also show the amount of extra effort that women must devote to their research to retain their top status in academia, and the extent that their recognition when in top positions is fragile compared to men. This study also confirms the cumulative advantage of creating a gender-inclusive culture that enables women to improve their scientific productivity and impact: such cultures tend to privilege first-author publications over patenting and thus prioritize a type of output where women have had more success. Finally, this paper concludes with policy recommendations for improving the number of women in research and the institutions where they work.

Keywords: Gender; Scientific production; Scientific impact; Nanotechnology

Introduction

Nanotechnology has been heralded by many as a revolutionary innovation for industrial production (Bhattacharyya et al. 2009; Roco 2017; Schulenburg 2004; Stix 2001). While still at an incipient stage, promoters of nanotechnology promise that it will spur economic growth and job creation in a variety of sectors including materials, medicine, and agriculture (Roco 2011). However, the possible economic benefits of nanotechnology could be undermined if nanotechnology negatively reinforces inequalities (Cozzens 2010), stigmatization and discrimination (UNESCO 2014). Therefore, the difficult challenge for science and technology policy is supporting nanotechnology innovation, while also considering its potential negative implications. This task is further complicated by the high degree of uncertainty that still surrounds nanotechnology and connected environmental, health, social and economic outcomes, as well as how those outcomes will be distributed within and between countries (Hankin and Read 2016). These could give rise to a "nano-divide" (Moore 2002; The Royal Society 2004), a term that alludes to the division of global society into individuals, groups or countries who will be advantaged or disadvantaged as a result of unequal access to nanotechnologies, as well as unequal opportunities to participate in research, development, and innovation (UNESCO 2014).

To help understand such policy decisions and to help guide nanotechnology innovation towards fair and sustainable outcomes, scholars have put forward several frameworks including inclusive innovation and responsible research and innovation (RRI) (Schroeder et al. 2016). RRI is a framework that is rooted in developed countries, and that aims to better align research and innovation (especially related to emerging technologies) with societal needs and expectations. One articulation of RRI—offered by the European Commission as a key action of the 'Science with and for Society' objective in the Horizon 2020 programme—incorporates the five dimensions of gender equality, science education, open access/open data, public engagement, and ethics (European Commission 2018).

Drawing on survey results and bibliometric data, this study sheds light on an important dimension of responsible research and innovation, gender equality, using Canada as a case study. Canada is a leading nation in nanotechnology, and has enacted several policies and programmes to spur nanotechnology research and development (Hu et al. 2012). In June 2016, the Government of Canada also launched an "inclusive innovation agenda" to develop a policy framework that promotes innovation and economic growth while ensuring that opportunities to benefit from and participate in innovation are available to all Canadians (Innovation, Science and Economic Development Canada 2016). One of the six primary action areas introduced in Canada's inclusive innovation agenda is to promote global science excellence, the explanation of which alludes briefly to RRI's gender inequality dimension and the shortage of women in Canadian science. This indicates that there is a clear need for the integration of gender dimensions into Canadian research programmes (similar to those gender-related objectives prioritized by the Council of the European Union (2015)).

In this regard, this study adopts a more comprehensive definition of the nano-divide that better conveys how divides can occur along multiple dimensions connected to who will and will not have access to, profit from, benefit from, and control of nanotechnologies (Sparrow 2007). The study specifically conceptualizes the nano-divide from a gender perspective: it analyzes how individuals profit differently from the nanotechnology scientific reward system in terms gender, status and/or institutional culture. This kind of analysis is essential because a shortage of women in the field not only impedes equity in the research workforce, it also means that women can end up benefiting less from nanotechnologies, and could thus exacerbate existing gender-related discrimination and stigmatization by furthering the negative stereotype that women are less technology-adept (UNESCO 2014).

The rest of the paper is structured as follows. First, the literature on the reward system of science and the 'gendered innovation' approach (Schiebinger 2017) is reviewed in order to provide the framework of the study. The methodological details of the survey and bibliometric analysis of Canadian researchers involved in nanotechnology R&D are then provided. The findings section explores how individuals are rewarded differently by gender, status and/or under different gender-related institutional cultures. This is followed by a discussion that offers conclusions and policy implications based on the results. Finally, the limitations of the research are discussed.

Conceptual framework

Reward system of science

This study is centered around the framework of the reward system of science, which was canonically described by Merton (1973). The scientific reward system is based on the ideal that the quest for peer recognition is the primary reason that scientists do research and that an equitable relationship exists between the contributions that scientists make and the recognition that they receive within the context of the scientific community (Gaston 1970; Merton 1968). The dominant way to operationalize and measure scientific reward is through authorship productivity and citation rates (Desrochers et al. 2018; Paul-Hus et al. 2017). These two metrics have been increasingly utilized to understand the extent a scientist is prolific, influential and recognized in the community. They, therefore, become data used to evaluate researchers and are inputs for key career decisions: hiring, reappointment, tenure, promotion, funding allocation (Holden et al. 2005) and salary (Toutkoushian 1994).

However, these two measures are not entirely neutral and hinge on the Matthew effect, a phenomenon coined by Merton (1968), which can be understood through well-known adage: "the rich get richer and the poor get poorer". Merton called attention to the unfairness in the recognition system, in the sense that recognition is often disproportionally accredited to renowned scientists for a similar work, leaving less-known and less-eminent scientists disadvantaged. However, for female scientists, the Matthew effect goes beyond under-recognition: the effect is systematic and represents repression or denial of women's contributions to science whose work is often attributed to their male peers. This is coined as the "Matilda effect" by Rossiter (1993), who elaborated on the importance of 'fairness' problems that operate in the opposite direction in relation to the Matthew effect.

These two elements of the reward system of science (authorship and citations) are thus reliant on factors related to both competence and fairness. This study, thus, characterizes the scientific reward system based on associations of competence and fairness with scientific recognition. The study seeks to understand whether these associations in the scientific reward system are different when considering gender of the scientist involved and the institutional culture where the scientist works. For this purpose, this paper utilizes the contextual strategic approaches found in the framework of gendered innovation. Accordingly, the next section provides a detailed explanation of this framework.

Gendered innovation

The term "gendered innovations" was coined by Londa Schiebinger in 2005 and is commonly used to discuss the integration of gender analysis into all phases of research, and specifically utilizing gender analysis as a resource to fuel new discoveries and the development of new technologies. Gender equality is becoming a high priority in RRI frameworks based on the idea that gendered innovations can be a catalyst for excellence in science and technology, improving science by removing gender bias from scientific discoveries (Rifà-Valls et al. 2013). Schiebinger identifies three strategic approaches (or levels of analysis) to gender in research, policy, and practice, along with three corresponding 'fixes': (1) Participation of women in science: fix the numbers of women; (2) Gender in the cultures of science and engineering: fix the institutions; and (3) Gender in the results of science: fix the knowledge. The first two approaches put the focus on the context of research, and the latter concentrates on the content of research, which is explained more in detail below.

Fix the numbers of women (participation of women in science): Schiebinger's first level of analysis examines women's involvement in science and engineering fields by studying the experiences of women in university, governmental labs and industry and proposing programs (e.g., funding allocation to women scientists) to ensure that women succeed in these fields. At this level, gender issues are described in the context of the so-called "glass ceiling" and "leaky pipeline". The concept of "glass ceiling" (Hymowitz and Schellhardt 1986) describes gender barriers that preclude women from being represented at high-level positions, and the "leaky pipeline" (Berryman 1983) describes how more women than men leave the scientific profession at every educational and career stage. UNESCO (2007, p. 120) associates the occurrence of these concepts and lack of representation of women in senior positions with gendered approaches to publication productivity patterns, and domestic and childrearing responsibilities, which emanate from traditional masculine discourse prevalent in the academic career system.

Fix the institutions (gender in the cultures of science and engineering): Gendered policies in science and engineering generally advocate for an increase in the number of women in science to remedy inequity and fix the issues caused by the leaky pipeline and glass ceiling. These policies typically place great emphasis on attracting more women into scientific fields and pay less attention to the workplace cultural factors that create gender biases both in numbers and scientific experiences (Bagilhole et al. 2008; Etzkowitz and Gupta 2006; Faulkner 2006). This sheds light on the importance of culture, which includes institutions, regulations, norms, values and implicit assumptions of a given society. The creation of masculine academic and organizational cultures impinges on women's participation and advancement in science, and affects their reputation as professionals in science and engineering fields. Some important cultural factors to allay these concerns are identified in Buré (2007), among which are work-life balance, support, and gender-inclusiveness.

Fix the knowledge (Gender in the results of science): The third level in the gendered innovation framework refers to how gender analysis can enhance knowledge production in science and engineering, noting that gender is a factor that shapes the content of science and can open new research avenues. Schiebinger & Klinge (2013) detailed state-of-the-art methods of sex and gender analysis and introduced several case studies in different fields, including nanotechnology, to demonstrate how the incorporation of gender analysis into research can result in the development of new knowledge and technologies, or in other words, the creation of gendered innovations.

It is important to note that “fix the numbers” and “fix the institutions” put the focus on the context of the research rather than the content and could thus serve as a baseline to provide gender analysis of the reward system of science, which as discussed above, operates within the social context of the scientific community. Thus, when this research explores how competence- and fairness-related associations in the reward system of science vary according to (1) gender and status, and (2) the institution’s culture, these two concerns map onto “fix the numbers” and “fix the institutions” respectively. While this study does not explicitly explore “fix the knowledge,” Schiebinger (2008) considers efforts to fix the first two levels (recruit and retain women in science) are crucial for the third level. This is because increasing the number of women in scientific professions opens the way to reconceptualizing science and engineering research. The association between female authorship and the incorporation of gender and sex analysis in scientific papers is widely discussed in Nielsen et al. (2017) and Sugimoto et al. (2019).

Methods

Operationalizing factors

Reward system of science:

We based our model on the Mertonian framework, which revolves around scientific contribution and peer recognition. This setting puts more focus on research than teaching, and considers scientific publication as the most important contribution that a scientist could make to the community (Gaston 1970), thus placing it at the heart of the reward system of science (Rosenbaum 2017).

Authorship and citations are the most common and longest-established elements of the scientific reward system (Cronin and Overfelt 1994; Díaz-Faes and Bordons 2017; Paul-Hus et al. 2017). These elements are indicative of scientific contribution and recognition respectively, based on which measurement of scientific performance is conducted. Given that scientific publishing is essential to all disciplines (it is not specific to a particular discipline) (Rosenbaum 2017) and nanotechnology is an interdisciplinary pursuit, the nanotechnology reward system is defined around two main indicators: (1) scientific output (number of publications per active year) as the measure of authorship productivity of a researcher, and (2) scientific impact (number of citations per active year) as a measure of influence and renown of a researcher among his/her scientific community.

In this research, competency is reflected through the extra scientific efforts that a researcher puts into his/her scientific pursuits; the extent a researcher promotes his/her work; and his/her scientific team size. Fairness is reflected through the extent of the diversity in his/her scientific team. In order to homogenously, objectively and clearly define these associations for each researcher, these factors are here defined based on bibliometric means and come from the literature as follows.

Because first authors have the highest share of contribution to a scientific paper (Larivière et al. 2016) and because patenting is a measure of how much researchers involve themselves in commercial activity, these two measures could both be considered as indicators of a researcher’s additional level of effort within scientific pursuits, which are relevant (especially in technological fields like nanotechnology) for career progress and are considered as legitimate forms of scientific competence when it comes to hiring, promotion and tenure decisions (Azoulay et al. 2007; Müller 2012). Collaboration also has close ties with competence (Gordon 1980) and is reflected in the number of co-authors, which is shown to be highly associated with productivity (Fanelli and Larivière 2016) and citation count (Biscaro and Giupponi 2014; Uddin et al. 2013) of a researcher. Self-promotion can be represented by self-citations in the context of scholarly communication (Hyland 2003). Self-citations have the potential to inadvertently or artificially inflate citation rates and raise the competence position of authors among their scientific community (Costas et al. 2010; Glänzel et al. 2006) and might, in turn, positively influence productivity. On the fairness-related associations, since women are highly underrepresented in science and since researchers form and repeat their scientific collaborations more often with men (Bozeman and Corley 2004; Ghiasi et al. 2015; Knobloch-Westerwick and Glynn 2013), gender diversity in scientific teams could be considered indicative of gender inclusion and fairness.

Gendered innovation: "Fix the numbers" is addressed by providing a gender analysis of differences of competency and fairness associations by seniority. The level of seniority is measured by academic ranking and level of funding in this study and these differences help better understand concerns around the glass ceiling and the leaky pipeline. Childrearing is one of the main driving forces of the attrition of women in science (Ogden 2012) and parenthood stage is thus controlled for at this level.

This paper addresses the "fix the institutions" level by considering whether the fairness- and competency-related associations in the reward system of science vary when the institutional culture is gendered. The gendered culture is determined by *the level of work-life balance*, using scales for difficulties a researcher perceives in balancing work and personal life, and in managing his/her career because of his/her spouse's/partner's career. The cultural *support* factor is reflected in the degree to which a researcher receives positive treatment from colleagues, and the *gender-inclusiveness* factor is defined in terms of women's representation in the workplace and a lack of gender-inclusive culture. More specifically, the former is defined as whether there are few women involved in the researcher's field and the latter is defined as whether there is a lack of gender-inclusive culture in the researcher's workplace. This research thus intends to reflect gender equity, and gender-inclusive culture is defined here as one that fosters the attitudes, values, and behaviors that are consistent with sustainable gender equity in the workplace.

Data

Nanotechnology researchers are identified using an all-nanotechnology article dataset developed by (Barirani et al. 2013; Moazami et al. 2015; Tahmooresnejad et al. 2015). This dataset is gathered from the Scopus database, which claims to provide comprehensive coverage of scientific publication data from 1996 (Elsevier 2016) and provides a larger journal coverage compared to Web of Science (Mongeon and Paul-Hus 2016). One of the advantages Scopus presents over other comprehensive publication databases, top among which is Web of Science, is its unique author identifier for each author. The Scopus Author identifier is a unique ID assigned to each author, based on which information on an author's research output can be obtained, including list of publications, citation metrics, current and previous affiliations, number of co-authors and the like.

7,343 authors are identified in the dataset who have at least one affiliation to a Canadian institution and who published more than two publications in the field of nanotechnology over the years 1996-

2011. In order to gather a list of researchers to whom to send the questionnaire, the email address of a researcher is identified by the email address listed on the most recent publication where the researcher is designated as a corresponding author by referring into the researcher’s Scopus author profile (using the Scopus Author Identifier). If not available, then the email was obtained by referring to the researcher’s academic and professional profiles (e.g., personal websites, LinkedIn profiles, affiliated institution websites, etc.). In the end, the questionnaire was sent to 6,606 valid email addresses, and 523 valid responses (out of 674 total) were collected. Invalid responses here correspond to duplicates and incomplete responses.

These 523 researchers identified themselves as active researchers in nanotechnology in Canada, and their bibliographical data was further collected by the use of their Scopus Author ID. Total number of publications, total number of citations, number of self-citations from all authors, number of self-citations from the selected author, number of co-authors, number of first-authored publications, and year of first and last publication (as of March 2016) are further assigned to each respondent. In accordance, career-age of each respondent (or the number of active years) is calculated as the number of years between the last and first publications of a scientist. The main discipline of research for each respondent is defined by the subject area in which highest proportion of his/her papers are published. This sample size is larger than the sample size that is representative of a population of 8000 individuals defined by Krejcie and Morgan (1970) (which is 367).

Data on patents was further collected through a manual search of the United States Patent and Trademark Office (USPTO). For this purpose, first, the researcher’s name, province, and country are matched with the inventor’s and, second, the similarity between abstract, title and subject area of their patents and their scientific papers are verified. In this research, gender is defined as binary and is assigned based on the first name of the respondents. Gender is further assigned to respondents and their primary co-authors, using the gender-checker name and gender database (http://genderchecker.com/). This database assigns gender to first names with high level of confidence and is based on 2001 and 2011 UK Census data, together with 2011 UN Census data and other online sources and thus accounts for names from cultures across the globe. For those whose gender remain unidentified or unisex, gender was assigned manually, using online academic or professional profiles. We also manually looked into the academic and professional profiles of participants and identified and verified their assigned gender for validation. The numbers of female and male respondents are, respectively, 92 and 431. This corresponds to the female to male ratio of publication productivity for nanotechnology, which is 0.258 for Canada in Larivière et al. (2013).

Moreover, the distribution of researchers across Canadian provinces and sectors in this sample is similar to that of Ghiasi et al. (2020), in which Canadian publications with pro-poor applications are analyzed. More details can be found in Appendix 1. Since 21% of participants were located in sectors in which teaching was not mainstream (i.e., governmental agencies, industry and hospitals) (Appendix 1) and since not all academic institutions are teaching-oriented, this study puts the main focus on research-related activities and teaching activities is not considered as a critical factor to differentiate women and men’s publication productivity.

Data for funding is collected through the Natural Sciences and Engineering Research Council of Canada (NSERC) and Social Sciences and Humanities Research Council (SSHRC) awards databases. Therefore, funding in this research refers to Canadian governmental funding awarded to the researchers in their scientific careers. The median of funding received in Natural Sciences and Engineering (NSE) is $143K for men and $100K for women (Larivière et al. 2011). In accordance, this study assumes that those researchers with equal or more than $100K of funding are highly funded researchers and those with less $100K of funding are low funded researchers.

The maximum number of co-authors recorded in Scopus is 150, and the first names of some of the co-authors were not listed in the Scopus. Therefore, the share of female co-authors in this study is the proportion of women among the main co-authors of the selected author. Scopus lists co-authors by the number of co-authored publications with the selected author, which is also referred to as the level of loyalty in this study. Therefore, for co-authors, gender is assigned to at least the top 15 loyal co-authors of a selected author to cover, at a minimum, the top 10% of major co-authors.

It is important to note that this study is not only based on the questionnaire data. It is the combination of survey, bibliographical, funding and patent data. One limitation for the data collected through databases (co-authors, for example) that must be acknowledged is the fact that there is no possible way to consider non-binary gender. These two ways for gender assignation (for respondents and their co-authors) needed to be aligned, we thus used both gender and name databases and professional profiles to assign gender, which is common best-practice in bibliometrics studies.

Other factors are collected through a questionnaire, covering two types of questions (1) facts and (2) perceptions. The former involves demographic information of active nanotechnology researchers, including their sector of affiliation, their highest educational degree, academic ranking, parenthood stage, and the like. The latter addresses gender-related cultural factors (work-life balance, support, and inclusiveness) through perceptions of researchers by posing six Likert-type questions, ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire also comprised a set of close-ended statements for each Likert-type question, which looked at the possible reasons that contributed to the respondent's rating. To note that the respondent had the freedom to choose none, one or more than one of these subfactors or they had the option to choose 'others' and name their own reasons. The choice of these subitems was inspired by Chaudhuri (2011) who addressed barriers in the career path of PhD students.

Model

The models are introduced in a way to address the concerns around the two fixes related to the scientific context: (1) fix the numbers and (2) fix the institutions. The models have two dependent variables: traditional research output measured by the number of documents per career-age, as well as the total number of citations per career-age. As previously mentioned, the former is a measure of authorship productivity of a researcher, whereas the latter is associated with the research impact of a scientist and indicates to what degree his/her research is influential. The two dependent variables present two criteria by which researchers are rewarded.

The dependent variables are better represented by a log-normal distribution, due to the skewness of their distributions. Since the natural logarithm of these variables follows a normal distribution, Ordinary Least Squares (OLS) regression modeling is applied in this study. Table 1 presents a list of independent variables, their descriptions, their mean for each gender and the significance level of differences between male and female researchers. Two measures of the distorted normal distribution, namely kurtosis and skewness, are calculated for each of the continuous independent variables to ensure that outliers are removed, and their distributions are closest to normal. The variables with large kurtosis or skewness are further transformed using either natural logarithm or inverse function, verifying that the distribution of the independent variables is closest to the normal distribution. Models are therefore expressed as:

(1)

$$\begin{pmatrix} nbPub/Careerage \\ nbCit/Careerage \end{pmatrix} = f\begin{pmatrix} nbPat, \dfrac{nbFAPub}{Careerage}, shareofAASelfCit, shareofSASelfCit, \\ \dfrac{nbCoaut}{Careerage}, shareofFcoaut, dChildmorethan1, \\ dFemale, dAcademicRank, dFund \end{pmatrix}$$

(2)

$$\begin{pmatrix} nbPub/Careerage \\ nbCit/Careerage \end{pmatrix} = f\begin{pmatrix} nbPat, \dfrac{nbFAPub}{Careerage}, shareofAASelfCit, shareofSASelfCit, \\ \dfrac{nbCoaut}{Careerage}, shareofFcoaut, \\ Balancediff, TreatPositive, WomenFew, GenderExclusive, Spousediff, \\ , dFemale \end{pmatrix}$$

All continuous explanatory variables in the models are transformed using the z-scores in order to minimize the multicollinearity problems. Table 2 verifies that the correlation coefficient among independents variables is very low, and variables are not correlated.

The moderating associations of gender, gender by academic rank and level of funding, and gender-related institutional cultural factors are also analyzed. More specifically, this study looks into interactions of *dFemale*, *dAcademicRank*, *dFund* to reflect the issues around "fix the numbers" (Fig 1) and *Balancediff*, *TreatPositive*, *WomenFew*, *GenderExclusive*, *Spousediff* with other continuous variables to address concerns over "fix the institutions" (Fig 2). These moderating effects help explain whether determinants and contributing factors of scientific reward for nanotechnology researchers differ for men and women (of different academic rank or funding), and what differences a more equitable context (mainstreaming of gender perspectives) might make in this reward system. To note that, since academic responsibilities are different by academic ranking, this paper controls both gender and ranking when considering career and personal life balance. However, the other institutional cultural factors are not reliant on academic ranking. For example, regardless of his/her academic ranking, a researcher is either involved in a dual career partnership or not. The same applies to supportive and gender-inclusive culture in the workplace.

Fig 1. Fix the numbers of women approach: direct and gender- and ranking- moderating associations between the elements of scientific reward system (scientific production and impact) and competence-based and fairness-based categories.

Fig 2. Fix the institutions approach: direct and gender-related cultural moderating associations between the elements of scientific reward system (scientific production and impact) and competence-based and fairness-based categories

Tables 3 and 4 reveal robust regression results with significant interaction terms for all models. More specifically, Columns Art2-Art3 and Cit1-Cit8 reflect the level “fix the numbers” and Columns Art4-Art8 and Cit10-Cit14 reflect the level “fix the institutions”. Columns Art1 and Cit9 reflect only direct associations when no moderating associations are considered. Male full professors and men with high level of funding are considered as the reference categories in the regression results included in this study. However, the significance level has been verified for other cohorts being considered as the reference category, and relevant tables are included in Appendix 2 (columns: Art-A) and Appendix 3 (columns: Cit-A).

Inverse interpretations are considered for variables with inverse transformation. Moderating effects are further plotted in MATLAB to help interpretations, taking into account *only* interacting variables. Therefore, it is important to note that these plots only show differences in the trends and hence, are not indicative of definitive quantities. All analyses are descriptive and exploratory. This paper considers the threshold of 0.1 as the significance level for regression analysis, since this study aims to *explore* effects and trends rather than to test inferences (similar to the approach of Thiriet et al. (2016) for exploring ecological trends). Moreover, because gender disparities in scientific publishing appear likely to persist for 26 years in nanotechnology (Holman et al. 2018), even weak associations are important to explore mechanisms for policy reforms in STI. Finally, it is important to clarify that, regression analysis only captures the relationship between the independent and dependent variables and does not show the causality of the relationship. Therefore, in this paper, impact (effect or influence) of an independent variable on a dependent variable does not imply any causality and merely refers to the degree of association between a dependent and an independent variable.

Table 1. List of variables, descriptions, gender means and comparison tests.

Dimension	Variable	Description	Men (n=431)	Women (n=92)	M-W[a]
Attributes	Careerage	year of last publication minus year of first publication plus one	22.45	18.38	0.00**
	nbPub/Careerage	total number of publications divided by career-age	4.03	2.86	0.00**
	nbCit/Careerage	total number of citations received to all publications divided by career-age	85.26	74.01	0.06
	nbPat	total number of patents	1.90	0.91	0.11
	nbCoaut/Careerage	total number of co-authors (max=150) divided by career-age	4.60	4.51	0.60
	nbFAPub/Careerage	total number of first-authored publications divided by career-age	0.91	0.63	0.02*
	shareofFcoaut	total number of female co-authors divided by co-authors of a researcher	0.14	0.18	0.00**
	shareofAASelfCit	total number of self-citations of all authors divided by total number of citations (also referred to as share of internal citations)	0.22	0.20	0.16
	shareofSASelfCit	total number of self-citations of a researcher divided by self-citations of all authors (referred to as share of author self-citations)	0.45	0.41	0.14
Culture	Balancediff	a five-point Likert scale showing the degree of difficulties a researcher face to balance his/her work and personal life	2.88	3.28	0.00**
	TreatPositive	a five-point Likert scale showing the degree of positive treatment received from colleagues of a researcher	3.94	3.79	0.05*
	WomenFew	a five-point Likert scale showing the degree to which field of the researcher is male-dominated	3.48	3.76	0.01**
	GenderExclusive	a five-point Likert scale showing the degree of gender equity practices applied in the workplace of the researcher	2.19	2.68	0.00*
	Spousediff	a five-point Likert scale showing the degree of difficulties a researcher face to manage his/her career because of his/her Spouse/partner	2.13	2.41	0.01*
Demographics	dFemale	dummy variable taking the value 1 if the researcher is female			
	dChildmorethan1	dummy variable taking the value 1 if the researcher has more than 1 child	0.58	0.37	0.00**
	dFullProf	dummy variable taking the value 1 if the researcher is a full professor	0.43	0.27	0.00**
	dAProf	dummy variable taking the value 1 if the researcher is an assistant or an associate professor	0.18	0.34	0.00**
	dOtherRes	dummy variable taking the value 1 if the researcher does not hold any professorship or tenure-track position	0.39	0.39	0.98
	dFund	dummy variable taking the value 1 if the researcher has received more than 100,000CAD for his/her research	0.50	0.52	0.69

*Notes: [a] Significance of the Mann-Whitney two-sample statistic to compare two populations (Note: *, ** show significance at the 0.01 and 0.05 levels respectively.)*

Table 2. Correlation table.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	ln((nbPub/Careerage)+1)	1																	
2	ln((nbCit/Careerage)+1)	.683**	1																
3	1/(nbPat+1)	-.219**	-.199**	1															
4	ln((nbCoaut/Careerage)+1)	.530**	.522**	-.105*	1														
5	1/((nbFAPub/Careerage)+1)	-.548**	-.409**	-.005	-.300**	1													
6	1/(shareofFcoaut+1)	.073	-.049	.035	-.086*	-.015	1												
7	1/(shareofAASelfCit+1)	-.101*	.291**	-.161**	-.059	.126**	-.028	1											
8	shareofSASelfCit	.470**	.210**	-.142**	.062	-.345**	-.021	-.125**	1										
9	Balancediff	-.011	-.021	.113**	.065	.042	-.070	-.023	-.056	1									
10	TreatPositive	.017	.059	-.004	.064	.046	.014	.046	-.044	-.123**	1								
11	WomenFew	-.004	-.052	.024	-.038	-.057	.122**	-.070	.069	.089*	.018	1							
12	GenderExclusive	-.086*	-.110*	.004	-.056	.001	.022	.021	.017	.143**	-.248**	.196**	1						
13	Spousediff	-.107*	-.128**	.021	.036	-.013	-.002	-.082	-.079	.259**	-.183**	.137**	.252**	1					
14	dFemale	-.158**	-.060	.071	-.015	.114**	-.145**	.062	-.061	.141**	-.073	.103*	.196**	.104*	1				
15	dChildmorethan1	.106*	.101*	-.130**	-.048	.032	.028	.093*	.140**	-.071	.011	-.018	-.054	-.148**	-.161**	1			
16	dFullProf	.347**	.299**	-.164**	.049	-.020	.008	.139**	.311**	-.023	.071	.034	-.108*	-.099*	-.126**	.155**	1		
17	dAProf	-.084	-.035	.149**	.006	-.023	-.046	-.056	-.007	.083	-.043	.066	.116**	.000	.152**	-.039	-.419**	1	
18	dOtherRes	-.279**	-.272**	.041	-.054	.039	.030	-.093*	-.307**	-.046	-.036	-.088*	.013	.100*	.001	-.124**	-.660**	-.406**	1
19	dFund	.230**	.194**	-.136**	.022	.069	-.027	.096*	.299**	-.003	.047	.114**	-.086*	-.152**	.017	.140**	.439**	.097*	-.522**

*Note: *, ** show Correlation is significant at the 0.01 and 0.05 level respectively.*

Descriptive statistics

Of the 523 respondents, 17.6% were women. Men were associated with older career-age and older stages of parenthood, which in this paper are determinants of the degree of maturity of a researcher. Men were involved in a higher rate of nanotechnology scientific production compared to women, but no difference in citation impact was found. Considering a researcher's additional level of activities in nanotechnology, there was no significant difference between the numbers of patents granted to men and women, while men were involved in the higher rate of first (lead) author production. Both internal citations and author self-citation rates were not different between the two genders (Table 1).

The perception of the institutional culture (Table 1) was more masculine for women compared to men: women had more difficulties in balancing their career and personal life, and they compromised their careers more to support their partner's career progression. Women perceived a lower level of support and positive treatment from their colleagues; they found themselves in a more male-dominated field, and they reported a lack of gender-inclusive initiatives and culture at a higher rate compared to men (Table 1).

To better understand the underlying reasons behind differences in perceptions for men and women, gender differences in related sub-factors are analyzed. Fig 3 presents the proportion of respondents of each gender who chose the selected sub-factor to the number respondents of each gender who chose 'agree' or 'strongly agree' for the selected Likert-scale question. For work and life balance, a higher share of researchers (both men and women) who have difficulty in balancing their work and personal life, reported struggling with taking additional work home and making time to spend with their families. Geographical constraint on the choice of an educational institution was considered as the main stressor for the career progression of dual-career couples/partners. In general, a higher share of women stated that they live separately from their partners and that they needed to interrupt their careers to follow their partners' relocation. Researchers who received support and positive treatment from their colleagues claimed that their gender has no impact on their collaboration opportunities and that their comments and suggestions are taken seriously by their colleagues. Women in a positive environment felt comfortable asking for help from their male colleagues, and they benefit from scientific advising from their colleagues at a higher rate. Moreover, 61% of women reported having the same opportunities as their male peers in a supportive environment. Researchers of both genders addressed the lack of representation of women among faculty members and research teams in male-dominated fields. However, women expressed their concerns over the underrepresentation of women in decision-making processes and the fact that the majority of decisions on their academic status and progress are made by their male peers. Among those researchers who identified themselves as working in a gender-exclusive culture, gender differences in perceptions were most different: women laid claim to fewer supports and opportunities and the need to devote extra effort to fill the same positions as their male peers and to be considered as professionals among their peers. However, men perceived that the gender-exclusive culture stems from women's lack of interest in science and engineering and the dearth of female role models in nanotechnology.

Fig 3. Share of respondents of each gender who chose the selected sub-factor to the number respondents of each gender who chose 'agree' or 'strongly agree' for the selected Likert-scale category.

Regression results

Competency and fairness associations in the reward system of science

The OLS regression results for the various factors associated with productivity (number of publications per career-age) of a researcher are presented in Table 3, and Table 4 exhibits regression results for the scientific impact of a researcher (number of citations per career-age).

Total number of patents, number of co-authors per career-age, and number of first-authored publications per career-age are positively associated with scientific productivity and scientific impact of nanotechnology researchers (Art-1, Cit-9). However, a higher share of female co-authors has a negative association with the productivity of researchers (Art-1). Yet, as a standalone variable, it does not have a significant association with the research impact of a researcher (Cit-9). This finding is in accordance with the associations of gender: being a woman is significantly and negatively associated with research productivity (Art-1) but presents no significant association with the citation impact of a researcher (Cit-9). Therefore, as women are significantly less productive, researchers who collaborate mainly with a higher share of women are also associated with lower scientific productivity[1].Share of internal citations has no significant association[2] with productivity (Art-1) and shows a significant negative association with the total scientific impact of a researcher (Cit-9). Higher share of author self-citations is associated with higher productivity (Art-1) and scientific impact of a researcher (Cit-9). This shows that the more internally a researcher "receives" citations, the lower is the impact of a researcher. However, the more author self-citations (rather than co-author self-citations), the more influential (i.e., a researcher with higher citation impact) and productive a researcher is. This highlights the value of self-promotion on boosting one's research impact. These findings confirm those of Costas et al. (2010) which found that the share of internal citations decreases as total impact of the paper increases and author self-citations increases as the productivity and academic rank grows. A higher percentage of author self-citations might be practiced among productive and more established researchers because these authors have more publications to cite. Therefore, author self-citations' association with an author's citation impact could present a considerable challenge to decision making for rewarding nanotechnology researchers.

The aforementioned interdependent variables show different patterns of associations when interacting with gender, academic rank and gender-related instituitional cultural measures.

Fix the numbers of women

Academic ranking

Male full professors publish significantly more than men and women of any academic ranking[3] (Art-2). The results for the scientific impact of researchers of different rankings show no

[1] It is important to note that the analyses presented in this study are at the author level rather than the article level (participants identified themselves as active researchers in the field of nanotechnology before entering the survey). Therefore, models are built to reflect the nano-divide from a gender perspective and is not on disciplinary gender differences. Despite this, even when controlling for disciplines, the results do not reveal any significant gender differences in productivity and citation impact of nanotechnology researchers of the same discipline (Appendix 4).

[2] Note that share of internal citations becomes significant in Table 3 when academic rankings of researchers of each gender are added to the model (Art-1, Art-4).

[3] This difference is weakly significant for female full professors.

significant difference between the research impact of women in any professorship ranks and male full professors (Cit-1).

When considering those researchers who are not in tenured or tenure-track positions, including postdocs or researchers (with a Ph.D. degree) who are affiliated to industry or governmental agencies, women are less productive (weakly significant) than their male peers (men of the same ranking) (Art-A3) and no significant gender difference is found between their citation impact (Cit-A3). However, when these female researchers get involved in patenting, they surpass (at a weak significance level) their male peers (men of the same ranking) in terms of scientific impact (Cit-A6). A higher rate of patenting and first-author productivity exacerbates the productivity gap[4] (Art-2) between female assistant and associate professors and male full professors. The association of patenting is even negative for female junior faculty. Although a higher number of co-authors is positively associated with the total impact of nanotechnology scientists (Cit-9), it favors publication impact of female junior professors less than men of any academic rankings (Cit-A8)[5]. On the other hand, when female junior professors co-author more papers with higher share of female researchers, their research becomes more recognized and generates more impact (Cit-A14) (at a weak significance level). However, as women climb in academic ranks, they comply with the male-dominated system and the share of female co-authors, thus, exhibits no association with total impact of female full professors (Cit-A13).

For female full professors, those who are involved in patenting are significantly more influential than men of any academic ranking (Cit-A4)[6]. While internal citations are associated with the lower scientific impact of a researcher (Cit-9), it is significantly associated with the lower impact of female full professors more than any other cohorts (except male assistant and associate professors) (Cit-A16)[7].

Funding

In this study, men with high levels of funding are most productive (Art-3) and their research has a higher impact compared to other cohorts[8], except for women with low level of funding (Cit-8). Women with a low level of funding are involved in (weakly) significantly higher impact research than men with low funding (Cit-A23) and when they become involved in more patenting activities, the impact of their work exceeds even that of men with high funding. Since patenting is associated with the higher scientific impact of women with low funding, this activity might play an important role in boosting the recognition of women and helping them raise more funding.

Women with a high level of funding are significantly less productive and less influential (at a weak significance level) than their male peers (Art-3, Cit-8). Although collaboration with higher numbers of researchers is associated with higher productivity and scientific impact of a researcher (Art-1, Cit-9), these networking activities (weakly) significantly benefit highly funded men at a higher rate than women of the same status.

[4] This difference is weakly significant.
[5] This difference is weakly significant for male assistant and associate professors.
[6] This difference is weakly significant for male professors.
[7] These results are weakly significant for male full professors and female assistant/associate professors.
[8] The difference is weakly significant for women with high level of funding.

Fix the institutions

Work and life balance

The association of patenting is higher (at a weak significance level) with the productivity of a researcher when he/she has difficulties in balancing her/his professional and personal life (Art-4) (Fig 4). However, it is more difficult for women to enter the patenting process due to its male-dominated culture. Therefore, patenting's association with higher productivity of researchers dealing with work-life balance might generate gender biases in productivity and benefit men more than women. The findings also reveal that having difficulties in work-life balance is most strongly associated with women in non-tenure track positions because their research impact is significantly lower compared to men of any position and ranking (Cit-A26)[9].

Fig 4. Association of difficulties in work-life balance with scientific production with respect to patents.

Positive treatment from colleagues

Receiving positive treatment from colleagues increases a researcher's scientific impact (but at a weak significance level). However, gender plays a moderating effect on the relationship between the receipt of positive treatments from colleagues and the researcher's total impact, and this relationship is adverse for women (Cit-11) (Fig 6a). This also shows that highly cited female and male researchers are not treated equally by their colleagues.

The positive association of the first-author production with productivity (Fig 5a) and citation impact (Fig 6b) is lower for a researcher who is receiving positive treatments from his/her colleagues (Art-5; Cit-11). In a 'positive' environment, researchers might be less required to devote extra effort to lead scientific papers and work harder in order to boost their productivity and impact, as opposed to the environments in which a researcher is not treated positively. Moreover, the negative association of the share of female co-authors with the productivity of a researcher is lower in a positive environment (Art-5) (Fig 5b).

The positive association of author self-citations with productivity (Art-5) (Fig 5c) and the negative association of internal citations with scientific impact are stronger (Cit-11) (Fig 6c) in the workplace environments where colleagues treat each other positively. One possible explanation is that positive relationships with colleagues could lead to more repeat collaborations or more loyalty with co-authors, and hence a researcher is more likely to be included in his/her co-authors' or colleagues' lead publications. Hence, a higher level of author self-citations is strongly associated with higher productivity of researchers in positive environments. On the other hand, loyalty forms a dense local cluster of researchers which could adversely affect the knowledge transmission (Zamzami and Schiffauerova 2017) and thus only promote internal recognition rather than external recognitions from the scientific community. Therefore, the higher share of internal citations is highly associated with lower citation impact.

Fig 5. Association of positive environment with scientific production with respect to (a: left) first-author production, (b: middle) share of female co-authors, and (c: right) share of selected author self-citations.

[9] The difference is weakly significant for male assistant/associate professors and men who are not in tenured or tenure track positions.

Fig 6. Association of (a: left) gender, and impact of positive environment with respect to (b: middle) first-author production, and (c: right) share of all authors' self-citations (internal citations) with scientific impact.

The representation of women

The analyses here reveal that the impact of first-author productivity (on total productivity) of researchers decreases as their workplace becomes more male-dominated. This could relate to the assumption that researchers who are located in male-dominated settings are able to delegate more, while researchers in gender-balanced fields might be required to work harder and lead more scientific papers (i.e., become involved in the higher rate of first-author productivity) to boost their productivity (Art-6) (Fig 7a).

Cross-citation analysis has shown a higher level of proximity and similarity for the nano-papers published in highly male-dominated fields (materials, chemistry, physics, and engineering fields) on the one hand, and for the nano-papers published in more gender-balanced and less productive fields (health and clinical research) on the other hand (Larivière et al. 2013; Porter and Youtie 2009). Therefore, researchers in less male-dominated disciplines are located in smaller and denser scientific networks where the share of nanotechnology papers produced in these disciplines is limited. Internal citations are thus inevitable in these fields (because there exists only limited number of relevant publications to cite) and thus are highly associated with the productivity of researchers. Therefore, the impact of internal citations is more positive and higher for less male-dominated fields (Fig 7b).

The positive impact of author self-citations on productivity decreases as the researcher's field becomes less male-dominated (Fig 7c), which shows that author self-citations play a more important role in male-dominated fields than in more gender-balanced fields.

Fig 7. Association of male-dominated fields with scientific impact with respect to (a: left) first-author production, (b: middle) share of all authors' self-citations (internal citations), and (c: right) share of selected author self-citations.

Gender-exclusive culture

The association of gender-exclusive culture with the scientific impact of a researcher is negative (Cit-13). The positive association of patents with productivity is highest (at a weak significance level) for researchers with gender-exclusive workplace culture (Art-7) (Fig 8a). In this culture, equitable measures are not considered to help women access the same opportunities, therefore patenting might be more rewarded and contribute positively to the researchers' overall productivity. However, for researchers with gender-inclusive workplace cultures, first-author production presents the strongest impact (at a weak significance level) on productivity (Art-7) (Fig 8b). Researchers working within these cultures might consider that it is easier for women to be involved in the first-author production rather than patenting, and therefore first-author production represents a more equitable pathway to achieve scientific reward.

Fig 8. Association of gender-exclusive culture with scientific production with respect to (a: left) patents and (b: right) first-author production.

Difficulties in managing career and life partnership

Difficulties in managing career and life partnership (including marriage) is significantly and negatively associated with productivity and impact of a researcher (Art-8; Cit-14) and women are facing this difficulty more than men in this study (Table 1).

The impact of patenting on the scientific production of a researcher is higher (at a weak significance level) for researchers facing difficulties in managing their career and partnership/marriage (Fig 9a). On the other hand, the association of first-author production and networking (collaborating with a higher number of co-authors) increases as a researcher's ability to manage his/her career and partnership/marriage increases (Fig 9b and 9c). These findings are similar to those on gender-inclusive culture (see the previous section), in the sense that the introduction of policies to support dual-career couples could open up a more equitable context (weighting the roles of first-author productivity and collaborations rather than patenting) for researchers to boost their productivity.

Fig 9. Association of difficulties in managing career and marriage/partnership with scientific impact with respect to (a: left) patents, (b: middle) first-author production, and (c: right) number of co-authors.

Table 3. Regression results for the number of publications per career-age (OLS).

ln((nbPub/Careerage)+1)	**(Art-1)**	**(Art-2)**	**(Art-3)**	**(Art-4)**	**(Art-5)**	**(Art-6)**	**(Art-7)**	**(Art-8)**
1/(nbPat+1)	-0.069***	-0.073***	-0.056***	-0.069 ***	-0.069 ***	-0.067***	-0.075 ***	-0.072 ***
	(0.016)	(0.024)	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
ln((nbCoaut/Careerage)+1)	0.224***	0.210***	0.280***	0.211 ***	0.231 ***	0.224***	0.230 ***	0.232 ***
	(0.016)	(0.016)	(0.028)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)
1/((nbFAPub/Careerage)+1)	-0.167***	-0.232***	-0.186***	-0.181 ***	-0.162 ***	-0.152***	-0.165 ***	-0.169 ***
	(0.017)	(0.025)	(0.017)	(0.017)	(0.017)	(0.018)	(0.017)	(0.017)
1/(shareofFcoaut+1)	0.056***	0.057***	0.056***	0.056 ***	0.053 ***	0.056***	0.053 ***	0.058 ***
	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)	(0.015)	(0.015)
1/(shareofAASelfCit+1)	-0.010	-0.077**	-0.021	-0.031 **	-0.006	-0.006	-0.009	-0.012
	(0.016)	(0.031)	(0.016)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)
shareofSASelfCit	0.166***	0.120***	0.161***	0.119 ***	0.168 ***	0.174***	0.157 ***	0.164 ***
	(0.017)	(0.018)	(0.025)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Balancediff				0.008				
				(0.015)				
TreatPositive					0.009			
					(0.015)			
WomenFew						-0.022		
						(0.016)		
GenderExclusive							-0.025	
							(0.015)	
Spousediff								-0.047 ***
								(0.015)
dFemale	-0.089**				-0.112 ***	-0.113***	-0.096 **	-0.092 **
	(0.042)				(0.040)	(0.041)	(0.041)	(0.041)
dChildmorethan1	0.071**	0.049	0.060**					
	(0.032)	(0.031)	(0.031)					
FemaleFullProf		-0.142*		-0.118 *				
		(0.074)		(0.071)				
MaleAProf		-0.241***		-0.263 ***				
		(0.049)		(0.047)				
FemaleAProf		-0.271***		-0.215 ***				
		(0.077)		(0.066)				
MaleOtherRes		-0.270***		-0.273 ***				
		(0.038)		(0.038)				
FemaleOtherRes		-0.384***		-0.383 ***				
		(0.070)		(0.064)				
FemaleHighFund			-0.149**					
			(0.059)					
MaleLowFund			-0.195***					
			(0.035)					
FemaleLowFund			-0.209***					
			(0.071)					
1/(nbPat+1) × *FemaleFullProf*		-0.075						
		(0.075)						
1/(nbPat+1) × *MaleAProf*		0.011						
		(0.051)						
1/(nbPat+1) × F*emaleAProf*		0.150*						
		(0.088)						
1/(nbPat+1) × *MaleOtherRes*		0.016						
		(0.035)						
1/(nbPat+1) × *FemaleOtherRes*		0.026						
		(0.068)						
1/((nbFAPub/Careerage)+1) × *FemaleFullProf*		0.077						
		(0.085)						
1/((nbFAPub/Careerage)+1) × *MaleAProf*		0.124**						
		(0.048)						
1/((nbFAPub/Careerage)+1) × F*emaleAProf*		0.132*						
		(0.074)						
1/((nbFAPub/Careerage)+1) × *MaleOtherRes*		0.069**						
		(0.035)						
1/((nbFAPub/Careerage)+1) × *FemaleOtherRes*		0.070						
		(0.066)						
1/(shareofAASelfCit+1) × *FemaleFullProf*		0.102						
		(0.094)						
1/(shareofAASelfCit+1) × *MaleAProf*		0.086						
		(0.051)						
1/(shareofAASelfCit+1) × F*emaleAProf*		0.033						
		(0.083)						
1/(shareofAASelfCit+1) × *MaleOtherRes*		0.043						
		(0.038)						
1/(shareofAASelfCit+1) × *FemaleOtherRes*		0.079						
		(0.057)						

ln((nbCoaut/Careerage)+1) × *FemaleHighFund*			-0.113*					
			(0.059)					
ln((nbCoaut/Careerage)+1) × *MaleLowFund*			-0.083**					
			(0.034)					
ln((nbCoaut/Careerage)+1) × FemaleLowFund			-0.081					
			(0.059)					
shareofSASelfCit × *FemaleHighFund*			0.025					
			(0.051)					
shareofSASelfCit × *MaleLowFund*			-0.077**					
			(0.035)					
shareofSASelfCit × FemaleLowFund			0.001					
			(0.064)					
Balancediff × *1/(nbPat+1)*				-0.027 *				
				(0.015)				
ln((nbCoaut/Careerage)+1) × *TreatPositive*					-0.009			
					(0.016)			
1/((nbFAPub/Careerage)+1) × *TreatPositive*					0.046 ***			
					(0.016)			
1/(shareofFcoaut+1) × *TreatPositive*					-0.032 **			
					(0.016)			
shareofSASelfCit × *TreatPositive*					0.030 **			
					(0.015)			
ln((nbCoaut/Careerage)+1) × 1/((nbFAPub/Careerage)+1)					0.081 ***		0.067 ***	
					(0.016)		(0.015)	
ln((nbCoaut/Careerage)+1) × 1/(shareofFcoaut+1)					0.039 ***			
					(0.015)			
ln((nbCoaut/Careerage)+1) × shareofSASelfCit					0.053 ***			
					(0.016)			
1/((nbFAPub/Careerage)+1) × shareofSASelfCit					0.026 *			
					(0.014)			
1/((nbFAPub/Careerage)+1) × WomenFew						0.052***		
						(0.015)		
1/(shareofAASelfCit+1) × WomenFew						0.030**		
						(0.015)		
shareofSASelfCit × WomenFew						0.040***		
						(0.015)		
1/(nbPat+1) × GenderExclusive							-0.029 *	
							(0.016)	
ln((nbCoaut/Careerage)+1) × GenderExclusive							-0.026	
							(0.017)	
1/((nbFAPub/Careerage)+1) × GenderExclusive							0.031 *	
							(0.016)	
1/(nbPat+1) × *Spousediff*								-0.029 *
								(0.016)
ln((nbCoaut/Careerage)+1) × *Spousediff*								-0.033 **
								(0.015)
1/((nbFAPub/Careerage)+1) × *Spousediff*								0.031 **
								(0.016)
Constant	1.385***	1.550***	1.480***	1.581 ***	1.461 ***	1.430***	1.443 ***	1.426 ***
	(0.025)	(0.032)	(0.031)	(0.025)	(0.018)	(0.017)	(0.017)	(0.017)
Nb observations	523	523	523	523	523	523	523	523
F	191.147***	33.613***	51.342***	67.472 ***	52.478 ***	69.503***	65.156 ***	70.216 ***
R^2	0.587	0.647	0.619	0.633	0.624	0.599	0.605	0.602
Adjusted R^2	0.580	0.628	0.607	0.623	0.612	0.591	0.596	0.593

Note: ***, **, * show significance at the 1%, 5% and 10% levels and standard errors are presented in parentheses.

Table 4. Regression results for the number of citations per career-age (OLS).

ln((nbCit/Careerage)+1)	**(Cit-1)**	**(Cit-2)**	**(Cit-3)**	**(Cit-4)**	**(Cit-5)**	**(Cit-6)**	**(Cit-7)**	**(Cit-8)**
1/(nbPat+1)	-0.071**	-0.095*	-0.067**	-0.073 **	-0.072 **	-0.069**	-0.066 **	0.001
	(0.033)	(0.050)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.050)
ln((nbCoaut/Careerage)+1)	0.443***	0.437***	0.479***	0.437 ***	0.447 ***	0.440***	0.440 ***	0.488 ***
	(0.034)	(0.034)	(0.063)	(0.034)	(0.034)	(0.034)	(0.034)	(0.060)
1/((nbFAPub/Careerage)+1)	-0.317***	-0.314***	-0.315***	-0.393 ***	-0.310 ***	-0.319***	-0.316 ***	-0.323 ***
	(0.036)	(0.036)	(0.036)	(0.053)	(0.036)	(0.036)	(0.036)	(0.036)
1/(shareofFcoaut+1)	-0.003	-0.007	0.002	-0.008	0.003	-0.005	0.002	0.004
	(0.032)	(0.032)	(0.032)	(0.032)	(0.050)	(0.032)	(0.032)	(0.032)
1/(shareofAASelfCit+1)	0.322***	0.317***	0.329***	0.321 ***	0.324 ***	0.333***	0.320 ***	0.360 ***
	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.066)	(0.033)	(0.033)
shareofSASelfCit	0.025	0.018	0.021	0.028	0.033	0.032	0.099 *	0.039
	(0.037)	(0.038)	(0.037)	(0.037)	(0.038)	(0.037)	(0.059)	(0.038)
dChildmorethan1	0.118*	0.123*	0.115*	0.114 *	0.109 *	0.117*	0.119 *	0.135 **
	(0.065)	(0.065)	(0.065)	(0.065)	(0.066)	(0.065)	(0.065)	(0.066)
FemaleFullProf	-0.159	-0.205	-0.158	-0.156	-0.159	-0.212	-0.110	
	(0.153)	(0.155)	(0.154)	(0.154)	(0.155)	(0.155)	(0.171)	
MaleAProf	-0.341***	-0.354***	-0.342***	-0.309 ***	-0.337 ***	-0.306***	-0.335 ***	
	(0.101)	(0.103)	(0.101)	(0.101)	(0.101)	(0.102)	(0.102)	
FemaleAProf	-0.197	-0.275*	-0.144	-0.216	-0.344 **	-0.177	-0.136	
	(0.142)	(0.155)	(0.144)	(0.144)	(0.164)	(0.147)	(0.146)	
MaleOtherRes	-0.511***	-0.513***	-0.511***	-0.506 ***	-0.509 ***	-0.510***	-0.473 ***	
	(0.081)	(0.081)	(0.081)	(0.081)	(0.081)	(0.081)	(0.082)	
FemaleOtherRes	-0.545***	-0.507***	-0.503***	-0.609 ***	-0.554 ***	-0.528***	-0.544 ***	
	(0.140)	(0.142)	(0.143)	(0.146)	(0.143)	(0.140)	(0.179)	
FemaleHighFund								-0.211 *
								(0.120)
MaleLowFund								-0.359 ***
								(0.074)
FemaleLowFund								-0.145
								(0.132)
1/(nbPat+1) × *FemaleFullProf*		-0.259*						
		(0.147)						
1/(nbPat+1) × *MaleAProf*		0.072						
		(0.109)						
1/(nbPat+1) × Fe*maleAProf*		0.248						
		(0.187)						
1/(nbPat+1) × *MaleOtherRes*		0.093						
		(0.075)						
1/(nbPat+1) × *FemaleOtherRes*		-0.188						
		(0.142)						
ln((nbCoaut/Careerage)+1) × *FemaleFullProf*			-0.010					
			(0.180)					
ln((nbCoaut/Careerage)+1) × *MaleAProf*			-0.062					
			(0.100)					
ln((nbCoaut/Careerage)+1) × Fe*maleAProf*			-0.336**					
			(0.148)					
ln((nbCoaut/Careerage)+1) × *MaleOtherRes*			-0.036					
			(0.079)					
ln((nbCoaut/Careerage)+1) × *FemaleOtherRes*			0.117					
			(0.127)					
1/((nbFAPub/Careerage)+1) × *FemaleFullProf*				0.068				
				(0.172)				
1/((nbFAPub/Careerage)+1) × *MaleAProf*				0.273 ***				
				(0.101)				
1/((nbFAPub/Careerage)+1) × Fe*maleAProf*				0.193				
				(0.156)				
1/((nbFAPub/Careerage)+1) × *MaleOtherRes*				0.039				
				(0.074)				
1/((nbFAPub/Careerage)+1) × *FemaleOtherRes*				0.261 *				
				(0.141)				
1/(shareofFcoaut+1) × *FemaleFullProf*					0.016			
					(0.143)			
1/(shareofFcoaut+1) × *MaleAProf*					0.008			
					(0.096)			
1/(shareofFcoaut+1) × Fe*maleAProf*					-0.270 *			
					(0.159)			
1/(shareofFcoaut+1) × *MaleOtherRes*					0.035			
					(0.079)			
1/(shareofFcoaut+1) × *FemaleOtherRes*					-0.076			
					(0.134)			

1/(shareofAASelfCit+1) × *FemaleFullProf*						0.377*		
						(0.193)		
1/(shareofAASelfCit+1) × *MaleAProf*						0.118		
						(0.106)		
1/(shareofAASelfCit+1) × Fe*maleAProf*						-0.096		
						(0.176)		
1/(shareofAASelfCit+1) × *MaleOtherRes*						-0.039		
						(0.080)		
1/(shareofAASelfCit+1) × *FelmaleOtherRes*						-0.162		
						(0.119)		
shareofSASelfCit × *FemaleFullProf*							-0.114	
							(0.156)	
shareofSASelfCit × *MaleAProf*							-0.246 **	
							(0.103)	
shareofSASelfCit × Fe*maleAProf*							-0.247	
							(0.153)	
shareofSASelfCit × *MaleOtherRes*							-0.027	
							(0.083)	
shareofSASelfCit × *FemaleOtherRes*							-0.100	
							(0.149)	
1/(nbPat+1) × *FemaleHighFund*								-0.125
								(0.122)
1/(nbPat+1) × *MaleLowFund*								-0.071
								(0.073)
1/(nbPat+1) × FemaleLowFund								-0.286 **
								(0.140)
ln((nbCoaut/Careerage)+1) × *FemaleHighFund*								-0.230 *
								(0.124)
ln((nbCoaut/Careerage)+1) × *MaleLowFund*								-0.063
								(0.073)
ln((nbCoaut/Careerage)+1) × FemaleLowFund								0.058
								(0.129)
1/(nbPat+1) × shareofSASelfCit								-0.095 ***
								(0.034)
ln((nbCoaut/Careerage)+1) × shareofSASelfCit								-0.082 ***
								(0.030)
Constant	4.177***	4.173***	4.178***	4.175 ***	4.179 ***	4.174***	4.151 ***	4.086 ***
	0.068	(0.068)	(0.068)	(0.068)	(0.068)	(0.068)	(0.069)	(0.066)
Nb observations	523	523	523	523	523	523	523	523
F	48.837***	35.426***	35.050***	35.441 ***	34.632 ***	35.379***	35.141 ***	32.587 ***
R^2	0.535	0.544	0.541	0.544	0.538	0.544	0.542	0.538
Adjusted R^2	0.524	0.529	0.526	0.529	0.523	0.528	0.526	0.521

Note: ***, **, * show significance at the 1%, 5% and 10% levels and standard errors are presented in parentheses.

Table 4. (Cont'd) Regression results for the number of citations per career-age (OLS).

ln((nbCit/Careerage)+1)	**(Cit-9)**	**(Cit-10)**	**(Cit-11)**	**(Cit-12)**	**(Cit-13)**	**(Cit-14)**
1/(nbPat+1)	-0.073**	-0.067 **	-0.078 **	-0.080**	-0.081 **	-0.081 **
	(0.034)	(0.033)	(0.034)	(0.034)	(0.034)	(0.034)
ln((nbCoaut/Careerage)+1)	0.462***	0.438 ***	0.463 ***	0.458***	0.453 ***	0.462 ***
	(0.035)	(0.034)	(0.035)	(0.035)	(0.034)	(0.034)
1/((nbFAPub/Careerage)+1)	-0.292***	-0.310 ***	-0.281 ***	-0.288***	-0.290 ***	-0.291 ***
	(0.037)	(0.036)	(0.037)	(0.037)	(0.037)	(0.036)
1/(shareofFcoaut+1)	-0.006	-0.001	-0.004	-0.001	0.000	-0.004
	(0.033)	(0.032)	(0.033)	(0.033)	(0.033)	(0.033)
1/(shareofAASelfCit+1)	0.362***	0.329 ***	0.375 ***	0.367***	0.370 ***	0.358 ***
	(0.034)	(0.033)	(0.034)	(0.034)	(0.033)	(0.033)
shareofSASelfCit	0.111***	0.034	0.128 ***	0.124***	0.125 ***	0.111 ***
	(0.036)	(0.037)	(0.035)	(0.036)	(0.035)	(0.035)
Balancediff		0.014				
		(0.051)				
TreatPositive			0.067 *			
			(0.037)			
WomenFew				-0.031		
				(0.033)		
GenderExclusive					-0.096 ***	
					(0.033)	
Spousediff						-0.111 ***
						(0.033)
dFemale	-0.057		-0.098	-0.077	-0.036	-0.055
	(0.088)		(0.088)	(0.088)	(0.089)	(0.087)
dChildmorethan1	0.150**					
	(0.068)					
FemaleFullProf		-0.170				
		(0.154)				
MaleAProf		-0.348 ***				
		(0.101)				
FemaleAProf		-0.137				
		(0.161)				
MaleOtherRes		-0.523 ***				
		(0.081)				
FemaleOtherRes		-0.516 ***				
		(0.143)				
Balancediff × FemaleFullProf		-0.098				
		(0.158)				
Balancediff × MaleAProf		-0.008				
		(0.093)				
Balancediff × FemaleAProf		-0.167				
		(0.137)				
Balancediff × MaleOtherRes		-0.030				
		(0.077)				
Balancediff × FemaleOtherRes		-0.371 **				
		(0.186)				
dFemale× TreatPositive			-0.152 *			
			(0.089)			
1/((nbFAPub/Careerage)+1)× TreatPositive			0.067 **			
			(0.033)			
1/(shareofAASelfCit+1)× TreatPositive			0.070 **			
			(0.034)			
Constant	3.899***	4.251 ***	3.977 ***	3.984***	3.977 ***	3.980 ***
	(0.053)	(0.055)	(0.036)	(0.036)	(0.036)	(0.036)
Nb observations	523	523	523	523	523	523
F	62.993***	34.473 ***	46.738 ***	61.998***	63.839 ***	64.630 ***
R^2	0.495	0.537	0.502	0.491	0.498	0.501
Adjusted R^2	0.487	0.522	0.491	0.483	0.491	0.494

Note: ***, **, * show significance at the 1%, 5% and 10% levels and standard errors are presented in parentheses.

Discussion and conclusions

This research draws upon the two approaches of the "gendered innovation" framework—namely 'fix the number of women' and 'fix the institutions'—and applies a gender dimension to questions about who drives nanotechnology and related scientific innovations and who is most likely to profit from the scientific reward system in nanotechnologies. The guiding assumption is that providing a more equitable context for women to engage, retain and thrive in nanotechnology will help strengthen nanotechnology capabilities in general. It develops a model for examining how the nanotechnology reward system is gendered and establishes a baseline from which policy changes can be initiated to tackle emerging inequities and/or foster gender equity—all of which are priorities for nanotechnology fields (Smith-Doerr 2011).

The descriptive results of this study reveal the scientific culture of nanotechnology was perceived as more masculine by women than by men. Women reported higher level of difficulties in balancing their career and personal life, either in general or more specifically, in managing their careers because of their spouse's/partner's career progression. Finding time for family and leisure, and geographical constraints on the choice of institutions with regard to a partner's career were among the most highlighted factors affecting work and life balance. Women perceived a lower level of support and less positive treatment from their colleagues, while a higher level of support was associated with equal opportunities for both genders and the fact that opinion and comments of a researcher are considered seriously by their colleagues. This is in line with the findings of Brainard et al. (2014) who found less informal support for female nanotechnology scientists in the US. Women found themselves in a more male-dominated field and raised the issues of the lack of representation of female faculty in their departments and the fact that decisions on their academic progress and status are made mostly by their male counterparts. Women also reported a lack of gender-inclusive initiatives at a higher rate compared to men. They expressed their concerns about less support and fewer opportunities in comparison to their male colleagues, and also about the extra effort they must devote to their work to attain the same positions as their male peers and to be perceived as professionals in the field. However, men strongly associated a gender-exclusive culture with a lack of female role models in nanotechnology and women's lower level of interest to enter this field. These results are consistent with previous studies on gender differences in perceptions of workplace climate and career development (Brainard et al. 2014; Bronstein and Farnsworth 1998; Gunter and Stambach 2005), according to which the climate of science is described as '*chilly*' for women and that a smaller share of women perceive their workplace to be a positive environment, because they experienced negative attitudes and exclusion by colleagues and unfairness in promotion processes.

Fix the numbers of women: women's involvement in nanotechnology

The regression analysis reveals that being a woman is associated with lower scientific productivity of a researcher. Accordingly, a higher level of co-authorship collaborations with women also shows a negative association with the scientific productivity of a researcher. This could create a negative cycle that results in the exclusion of women from co-authorship collaboration teams. This is an area where policymakers can explore mechanisms to fix the numbers by encouraging the inclusion of women in scientific collaborations and also to break the cycle. One example could be reflected in the accommodation of gender inclusion in the regulations on graduate student supervision or on collaboration with other researchers in funding, appointments, promotion, and tenure criteria and procedures.

When controlling for the academic status of researchers, differences in the scientific impact are not conspicuous as in the average annual scientific productivity between male full professors and women in any professorship rank. This finding highlights the important role of female junior faculty, as their publications receive citations at a similar rate as men in the highest academic rank. However, female junior faculty (i.e., assistant and associate professors) are placed in the disadvantaged position, in the sense that their productivity benefits less from first-author publishing and patenting, and their scientific impact also benefits less from collaborative research compared to other types of researchers. These results are in line with the findings of Besselaar and Sandström (2017), which suggest that the general lower academic rank of women and their lower prevalence in leading roles have a negative association with their performance which in turn reinforces lower academic status. These results are consistent with the reduced opportunities that women have in order to become a highly productive researcher (compared to men), explain the reasons behind the persistence of the glass ceiling in academia, and account for invisibility and exclusion of junior female academics from effective and collaborative research. These findings shed light on fixing the numbers by reinforcing policies to ensure retention of women in academia, which could be articulated as incorporation of equity considerations in promotion and tenure criteria, especially when peer review-based and citation-based measures are taken into considerations.

It is also shown that a higher rate of collaboration with female co-authors is associated with a larger scientific impact and more recognition for female junior professors compared to men of any academic ranking. One possible explanation is that female researchers tend to include a higher share of women in their co-authorship collaboration teams (Ghiasi et al. 2015) and form stronger ties with them (Ozel et al. 2014). However, as women's status rises in academia, the inclusion of a higher rate of female (main) co-authors is no longer positively associated with a higher impact for female full professors. Women are found to be more likely to receive tenure when they co-author with women (Sarsons 2017) and therefore, this finding emphasizes on fixing the numbers by showing the possibility that having female peers in research teams is key at an early stage of their careers to enhance female junior professors' career aspirations and confidence in their contribution. This could be framed as a policy suggestion: in order to increase the prevalence of women at higher positions, investments in resources are needed to build formal platforms and to create opportunities and incentives for junior female researchers to collaborate with other female peers.

Along these lines, for female senior faculty (female full professors), the citation impact of their publications surpasses those of men of any ranking when they become involved in patenting. This can be explained by the selection effect. Women are more likely to be highly competent in their work in order to break the glass ceiling to reach top positions in academia and become involved in patenting, a male-dominated scientific activity. However, while a higher rate of internal citations is associated with lower scientific impact of a researcher, it is most adversely associated with research impact of female senior faculty. It is shown that women need to be exceptionally competent to climb the academic ladder and become full professors (Toren 1988) and women self-cite at a lower rate than their male counterparts (King et al. 2017). This can be interpreted to mean that women's recognition and scientific impact in top academic positions is most susceptible to the disadvantages that a high rate of internal citations imposes on research impact of scientists.

Therefore, one implication of fixing the numbers here could be addressed by giving visibility to the work of women out of their immediate network through extensive media coverage, scientific exchange and networking events, and introduction of mobility facilitation actions for women.

Similar results are found when controlling for the level of funding. Involvement in patenting is more strongly associated with the scientific impact of women with low level of funding than their male peers and thus will improve their chances to raise future funding. However, women with high levels of funding are less productive and influential than men with high levels of funding, and networking and collaborative research privileges those men more than women. This could have the consequence of hampering the ability of women to raise further funding. Funding is a driving force for scientific performance in Canadian nanotechnology (Tahmooresnejad et al. 2015; Tahmooresnejad and Beaudry 2015), and higher scientific performance leads to more funding (Ebadi and Schiffauerova 2015). The gender gap in both research performance and funding has the potential to exclude women from this virtuous circle and bring more funding opportunities to men who already have high levels of funding. These findings clearly indicate the need to change policies in order to fix the numbers in inventions and to provide opportunities for women to raise funding for research, which could be articulated in the form of introduction of supporting programmes for women to collaborate and engage with industry.

Fix the institutions: gender in the culture of nanotechnology

Female junior faculty when struggling with work-life balance is associated with lower scientific impact compared to men of any ranking, which could present significant consequences for their tenure or promotion evaluations. This sheds light on the importance of work-life balance initiatives, which could be reflected in more flexibility toward tenure and promotion requirements, especially toward the research and teaching loads, and the tenure clock. Difficulties in balancing a career and marriage/partnership, more specifically, are associated with higher proportion of women, and lower productivity and scientific impact of a scientist. Organizations and academic institutions thus should be aware of and receptive to the need for policy reforms that support dual-career academic partnerships to ensure equal career opportunities for the scientist and his/her partner/spouse.

This study confirms that a supportive and positive working environment could contribute to increased recognition and higher citation impact for a nanotechnology scientist. However, highly cited women are treated poorly by their colleagues, while highly cited men are treated positively. This might be associated with ‘tokenism’ phenomenon, highlighting the extra pressure token women (women in the minority) experience because of their disproportionate representation and higher visibility, which often leads to exclusion and isolation from their peer group, and ultimately results in low recognition from their community (Kanter 1977). However, these lower levels of attention and recognition in the longer term might leave women more vulnerable to retain their recognition as highly cited researchers. In an isolating and unsupportive scientific environment, first-authorship is strongly associated with higher productivity. In other words, scientists might be required to devote extra effort and lead scientific papers to designate themselves as productive and high impact scholars in this setting. On the other hand, in a positive and supportive environment, collaboration with women does not present staggering negative associations with the productivity of a researcher and is thus more facilitated in this environment. This implies that a positive and supportive environment could provide the basis for forming more gender-balanced authorship teams—an important factor that might help to break the vicious cycle around collaboration with women and productivity. These findings call for the introduction of more systematic institutionalized support system for women scientists that, if continuous and consistent, could strengthen women's scientific capacity and impact.

This paper also reveals that in a more gender-balanced setting, the association of first-author production with the scientific productivity of a scientist is higher. This might be due to the fact that the nanotechnology scientific system has accommodated a considerably higher number of men than women in both authorship (Mihalcea et al. 2015) and inventorship (Meng and Shapira 2011), and therefore, researchers in a more gender-balanced field might need to make more efforts to compensate the gendered cultural differences of their workplace and their research community. Moreover, a higher rate of internal citation is associated with higher scientific productivity of a researcher in gender-balanced fields. This suggests a smaller and denser network of citations and authorship across more gender-balanced fields (i.e., health and clinical research) (Larivière et al. 2013; Porter and Youtie 2009). This might yield closer research topics and collaborations between nanotechnology scientists, and productive researchers are thus less likely to cite nanotechnology research outside their immediate connections. On the other hand, author self-citation rate is more associated with increased productivity of nanotechnology scientists working in male-dominated fields. This might be related to the higher propensity of men to self-cite their own papers (King et al. 2016) and greater likelihood for women to receive self-citations from their co-authors (Ghiasi et al. 2016). Therefore, in male-dominated fields, author self-citations are more associated with higher productivity rates for researchers.

This study also confirms the importance of implementing gender-inclusive initiatives in institutions, since highly cited scientists are most strongly associated with gender-inclusive workplace cultures. The existence of a gender-inclusive culture conforms to the accommodation of equitable measures in the workplace of a researcher. This might expose publications of a researcher (of any gender) to a larger community (including both men and women) and hence might reward a researcher with increased visibility and recognition. Furthermore, the association of first-author production rate with productivity is the highest for nanotechnology scientists conducting research in workplaces with a gender-inclusive culture, whereas the association of inventorship is the strongest for scholars working in a gender-exclusive culture. This finding suggests a possible cumulative advantage of the creation of gender-inclusive culture, in which first-author productivity is more extensively rewarded than patenting, thus reinforcing a more equitable context as it is easier for women to engage in the first-author production.

Prospects for policy development

This paper lays out a potential policy framework for gender equity and inclusion in Canadian nanotechnology. Thus, for the first time, a systematic and comprehensive gendered analysis of scientific productivity and impact of nanotechnology research is carried out which serves as stimulation for further research on how to incorporate gender equity policies into other emerging fields.

One the one hand, Canada's R&D efforts in nanotechnology are long established and prestigious, including founding the Centre for Advanced Nanotechnology at the University of Toronto in 1997, and the National Research Council (NRC) institutes in Alberta, British Colombia, Quebec, and Ontario, and introducing large institutions such as National Institute for Nanotechnology (NINT) and NanoQuébec (established in 2001). On the other hand, Canada's efforts to promote careers for women in science and engineering are implemented mainly through the Natural Sciences and Engineering Research Council of Canada (NSERC) research chair program for Women in Science and Engineering and partial investments in programs such as PromoScience and CREATE. However, despite all these efforts, initiatives to mainstream gender in nanotechnology R&D are nonexistent at national, institutional, and organizational levels.

The results of this study could have strong implications for policy development targeting gender equity. More specifically, this study calls for policy interventions to address gendered perceptions of the scientific culture, the potent disadvantages induced by vicious circles around lower productivity and collaboration with women, and women's difficulties in changing and retaining their status as top scientists, and suggests that policies supporting dual-career partnership and/or gender-inclusive culture have the potential to reinforce a more equitable context for women to boost their scientific performance.

To summarize, this paper aims to address 'fix the numbers of women' in Canadian nanotechnology by suggesting several policy recommendations (1) to provide a systematic support for women to get involved in inventorship and become more active in patenting (2) to incorporate gender diversity in supervisory or collaboration regulations in funding or tenure requirements (3) to consider equitable measures in evaluations when peer review-based and citation-based measures are taken into considerations (4) to provide visibility to the work of woman through various dissemination channels. This paper also shows that the reward system of science presents different levels of interactions under different institutional cultures. Most importantly, this paper suggests that increase in quotas, as a standalone variable, is not sufficient, and it could lead to a smaller and denser network within the community, in which researchers need to devote extra efforts to compensate the differences in cultures. Consequently, there is a clear need for the introduction of policies to change the culture to be more accepting of gender-inclusive initiatives in an institution, particularly in the aspect of family-friendly policies and women's progression. This research claims that under these initiatives, equitable context for women could be found in the scientific reward system.

Research limitations

This study does not look into the 'fix the knowledge' level of analysis covered in the gendered innovation framework, because the Mertonian scientific reward system is defined around the context of scientific research rather than the content, and this level puts focus on the content of the research. This is also accompanied by one methodological limitation that Scopus does not provide access to the full text of the papers, which is essential to this level of analysis. In this study, scientific productivity of a researcher is measured as a fraction of total number of publications he/she has published, and there is no indication whether all these publications are nanotechnology-related. However, all researchers have identified themselves, in the questionnaire, as active nanotechnology researchers. Since gender is defined based on the first name of the researchers, non-binary genders are not considered in this context. However, we believe non-binary gender, being very important, could relate to another important study onto itself, which could open up a new avenue for future research. Parental leaves are not deducted from the career age, which could result in underestimation of the scientific performance of researchers (especially for women). This paper measures only first-author productivity (leading scientific papers) and patenting (inventing) as extra efforts in academic activities. However, last- or corresponding authorship might also be associated with the supervisory role of a research project. Since there is no official practice in authorship order for assigning the primary investigator (or supervisor) of the research project (Tscharntke et al. 2007), last or corresponding authorship could be linked to an author who actually has made the least contribution or is only responsible for correspondence. Therefore, this paper takes into account only first-authorship as a measure of extra effort into research, because it signifies the author who made the largest contributions to the tasks performed in a paper (Larivière et al. 2016). Moreover, the co-author list in Scopus contains maximum 150 co-authors and thus, in this research, the maximum number of co-authors is 150. Lastly, this study uses an exploratory approach to provide a better understanding on potential gender influences on nanotechnology's scientific reward system and assumes that even weak associations are important in order to explore more inclusive policy mechanisms. Therefore, it includes the effects and trends that have weak (levels of) significance and the p-value threshold for a statistically significant result is considered to be 10%. These significant associations highlight a salient subset of gendered cultural and scientific factors and causality relations between these factors and scientific performance need to be addressed in future studies.

References

Azoulay, P., Ding, W., & Stuart, T. (2007). The determinants of faculty patenting behavior: Demographics or opportunities? *Journal of economic behavior & organization*, *63*(4), 599–623.

Bagilhole, B., Powell, A., Barnard, S., & Dainty, A. (2008). Researching cultures in science, engineering and technology: an analysis of current and past literature. *UK resource centre for women in science, engineering and technology*. http://www.wisecampaign.org.uk/files/useruploads/files/resources/report_7__bagilhole_1606_08.pdf. Accessed 18 June 2014

Barirani, A., Agard, B., & Beaudry, C. (2013). Discovering and assessing fields of expertise in nanomedicine: a patent co-citation network perspective. *Scientometrics*, *94*(3), 1111–1136.

Berryman, S. E. (1983). *Who Will Do Science?: Minority and Female Attainment of Science and Mathematics Degrees: Trends and Causes*. New York: Rockefeller Foundation.

Besselaar, P. van den, & Sandström, U. (2017). Vicious circles of gender bias, lower positions, and lower performance: Gender differences in scholarly productivity and impact. *PLOS ONE*, *12*(8), e0183301. https://doi.org/10.1371/journal.pone.0183301

Bhattacharyya, D., Singh, S., Satnalika, N., Khandelwal, A., & Jeon, S.-H. (2009). Nanotechnology, big things from a tiny world: a review. *Nanotechnology*, *2*(3), 29–38.

Biscaro, C., & Giupponi, C. (2014). Co-Authorship and Bibliographic Coupling Network Effects on Citations. *PLOS ONE*, *9*(6), e99502. https://doi.org/10.1371/journal.pone.0099502

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: implications for scientific and technical human capital. *Research policy*, *33*(4), 599–616.

Brainard, S. G., Allen, E., Savath, V., & Cruz, S. (2014). Factors and perspectives influencing nanotechnology career development: Comparison of male and female academic nanoscientists. *Journal of Women and Minorities in Science and Engineering*, *20*(1). https://doi.org/10.1615/JWomenMinorScienEng.2014006377

Bronstein, P., & Farnsworth, L. (1998). Gender differences in faculty experiences of interpersonal climate and processes for advancement. *Research in Higher Education,* *39*(5), 557–585.

Buré, C. (2007). Gender in/and science, technology and innovation policy: An overview of current literature and findings. *Strategic Commissioned Paper for: Innovation, Policy and Science Program Area International Development Research Centre (IDRC). Downloaded on*, *24*(02), 2012.

Chaudhuri, D. (2011). *Chaudhuri, Dola. Career path barriers of women doctoral students in STEM (science, technology, engineering, mathematics) disciplines*. Arizona State

University. Retrieved from https://repository.asu.edu/attachments/56872/content/Chaudhuri_asu_0010N_10838.pdf

Costas, R., Leeuwen, T. N. van, & Bordons, M. (2010). Self-citations at the meso and individual levels: effects of different calculation methods. *Scientometrics*, *82*(3), 517–537. https://doi.org/10.1007/s11192-010-0187-7

Council of the European Union. (2015). *Advancing gender equality in the European Research Area - Council conclusions*. http://data.consilium.europa.eu/doc/document/ST-14846-2015-INIT/en/pdf. Accessed 29 November 2019

Cozzens, S. (2010). Building equity and equality into nanotechnology. In *Nanotechnology and the challenges of Equity, Equality and Development* (pp. 433–446). Springer. http://link.springer.com/chapter/10.1007/978-90-481-9615-9_26. Accessed 17 February 2016

Cronin, B., & Overfelt, K. (1994). Citation-based auditing of academic performance. *Journal of the American Society for Information Science*, *45*(2), 61–72.

Desrochers, N., Paul-Hus, A., Haustein, S., Costas, R., Mongeon, P., Quan-Haase, A., et al. (2018). Authorship, citations, acknowledgments and visibility in social media: Symbolic capital in the multifaceted reward system of science. *Social Science Information*, *57*(2), 223–248. https://doi.org/10.1177/0539018417752089

Díaz-Faes, A. A., & Bordons, M. (2017). Making visible the invisible through the analysis of acknowledgements in the humanities. *Aslib Journal of Information Management*. https://doi.org/10.1108/AJIM-01-2017-0008

Ebadi, A., & Schiffauerova, A. (2015). How to Receive More Funding for Your Research? Get Connected to the Right People! *PLOS ONE*, *10*(7), e0133061. https://doi.org/10.1371/journal.pone.0133061

Elsevier, B. V. (2016). *Scopus Content Coverage Guide*. Amsterdam: Elsevier BV.

Etzkowitz, H., & Gupta, N. (2006). Women in science: a fair shake? *Minerva*, *44*(2), 185–199.

European Commission. (2018). Responsible Research and Innovation. http://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation. Accessed 23 May 2018

Fanelli, D., & Larivière, V. (2016). Researchers' Individual Publication Rate Has Not Increased in a Century. *PLOS ONE*, *11*(3), e0149504. https://doi.org/10.1371/journal.pone.0149504

Faulkner, W. (2006). Genders in/of engineering. *A reserach report. ESRC Economic & Social Research Council*. http://www.aog.ed.ac.uk/__data/assets/pdf_file/0020/4862/FaulknerGendersinEngineeringreport.pdf. Accessed 18 June 2014

Gaston, J. (1970). The Reward System in British Science. *American Sociological Review*, *35*(4), 718–732. https://doi.org/10.2307/2093947

Ghiasi, G., Harsh, M., & Schiffauerova, A. (2020). A cross-dimensional analysis of nanotechnology and equality: examining gender fairness and pro-poor potential in Canada's R&D landscape. *Journal of Responsible Innovation*, *7*(3), 528–552.

Ghiasi, G., Larivière, V., & Sugimoto, C. R. (2015). On the Compliance of Women Engineers with a Gendered Scientific System. *PloS one*, *10*(12), e0145931.

Ghiasi, G., Larivière, V., & Sugimoto, C. R. (2016). Gender differences in synchronous and diachronous self-citations. In *Proceedings of the 21st International Conference on*

Science and Technology Indicators, Valencia, Spain. http://crc.ebsi.umontreal.ca/files/sites/60/2016/09/Ghiasi-et-al._STI2016.pdf

Glänzel, W., Debackere, K., Thijs, B., & Schubert, A. (2006). A concise review on the role of author self-citations in information science, bibliometrics and science policy. *Scientometrics*, *67*(2), 263–277.

Gordon, M. (1980). A critical reassessment of inferred relations between multiple authorship, scientific collaboration, the production of papers and their acceptance for publication. *Scientometrics*, *2*(3), 193–201. https://doi.org/10.1007/BF02016697

Gunter, R., & Stambach, A. (2005). Differences in men and women scientists' perceptions of workplace climate. *Journal of Women and Minorities in Science and Engineering*, *11*(1). https://doi.org/10.1615/JWomenMinorScienEng.v11.i1.60

Hankin, S. M., & Read, S. A. K. (2016). Governance of Nanotechnology: Context, Principles and Challenges. In *Managing Risk in Nanotechnology* (pp. 29–49). Springer, Cham. https://doi.org/10.1007/978-3-319-32392-3_3

Holden, G., Rosenberg, G., & Barker, K. (2005). Bibliometrics: A potential decision making aid in hiring, reappointment, tenure and promotion decisions. *Social work in health care, 41*(3–4), 67–92.

Holman, L., Stuart-Fox, D., & Hauser, C. E. (2018). The gender gap in science: How long until women are equally represented? *PLOS Biology*, *16*(4), e2004956. https://doi.org/10.1371/journal.pbio.2004956

Hu, G., Carley, S., & Tang, L. (2012). Visualizing nanotechnology research in Canada: evidence from publication activities, 1990–2009. *The Journal of Technology Transfer*, *37*(4), 550–562. https://doi.org/10.1007/s10961-011-9238-3

Hyland, K. (2003). Self-citation and self-reference: Credibility and promotion in academic publication. *Journal of the American Society for Information Science and technology*, *54*(3), 251–259.

Hymowitz, C., & Schellhardt, T. D. (1986). The glass ceiling: Why women can't seem to break the invisible barrier that blocks them from the top jobs. *The Wall Street Journal*, *57*(D1), D4–D5.

Innovation, Science and Economic Development Canada. (2016). An inclusive innovation agenda: the state of play. https://www.ic.gc.ca/eic/site/062.nsf/vwapj/Inclusive_Innovation_Agenda-eng.pdf/$file/Inclusive_Innovation_Agenda-eng.pdf. Accessed 25 November 2019

Kanter, R. M. (1977). Men and women of the corporation. New York: Basic Books.

King, M. M., Bergstrom, C. T., Correll, S. J., Jacquet, J., & West, J. D. (2016). Men set their own cites high: Gender and self-citation across fields and over time. *arXiv preprint arXiv:1607.00376*. https://arxiv.org/abs/1607.00376

King, M. M., Bergstrom, C. T., Correll, S. J., Jacquet, J., & West, J. D. (2017). Men Set Their Own Cites High: Gender and Self-citation across Fields and over Time. *Socius*, *3*, 2378023117738903. https://doi.org/10.1177/2378023117738903

Knobloch-Westerwick, S., & Glynn, C. J. (2013). The Matilda Effect-Role Congruity Effects on Scholarly Communication: A Citation Analysis of Communication Research and Journal of Communication Articles. *Communication Research*, *40*(1), 3–26. https://doi.org/10.1177/0093650211418339

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and psychological measurement*, *30*(3), 607–610.

Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C. R. (2016). Contributorship and division of labor in knowledge production. *Social Studies of Science*, *46*(3), 417–435. https://doi.org/10.1177/0306312716650046

Larivière, V., Ni, C., Gingras, Y., Cronin, B., & Sugimoto, C. R. (2013). Bibliometrics: Global gender disparities in science. *Nature*, *504*(7479), 211–213. https://doi.org/10.1038/504211a

Larivière, V., Vignola-Gagné, E., Villeneuve, C., Gélinas, P., & Gingras, Y. (2011). Sex differences in research funding, productivity and impact: an analysis of Québec university professors. *Scientometrics*, *87*(3), 483–498.

Meng, Y., & Shapira, P. (2011). Women and patenting in nanotechnology: Scale, scope and equity. In *Nanotechnology and the challenges of equity, equality and development* (pp. 23–46). Springer. http://link.springer.com/chapter/10.1007/978-90-481-9615-9_2. Accessed 6 January 2014

Merton, R. K. (1968). The Matthew Effect in Science: The reward and communication systems of science are considered. *Science*, *159*(3810), 56–63. https://doi.org/10.1126/science.159.3810.56

Merton, R. K. (1973). *The sociology of science: Theoretical and empirical investigations*. University of Chicago press.

Merton, R. K., & others. (1968). The Matthew effect in science. *Science*, *159*(3810), 56–63.

Mihalcea, R., Moghe, P., & Burzo, M. (2015). Women in Mechanical Engineering: The Gender (Im) balance by the Numbers. *Ann Arbor*, *1001*, 48109.

Moazami, A., Ebadi, A., & Schiffauerova, A. (2015). A network perspective of academiaindustry nanotechnology collaboration: A comparison of Canada and the United

States. *Collnet Journal of Scientometrics and Information Management*, *9*(2), 263–293. https://doi.org/10.1080/09737766.2015.1069966

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*, *106*(1), 213–228. https://doi.org/10.1007/s11192-015-1765-5

Moore, F. N. (2002). Implications of nanotechnology applications: using genetics as a lesson. *Health Law Rev*, *10*(3), 9–15.

Müller, R. (2012). Collaborating in Life Science Research Groups: The Question of Authorship. *Higher Education Policy*, *25*(3), 289–311. https://doi.org/10.1057/hep.2012.11

Nielsen, M. W., Andersen, J. P., Schiebinger, L., & Schneider, J. W. (2017). One and a half million medical papers reveal a link between author gender and attention to gender and sex analysis. *Nature Human Behaviour*, *1*(11), 791–796. https://doi.org/10.1038/s41562-017-0235-x

Ogden, L. E. (2012). Leaky pipelines for Canadian women in research. *Nature News Blog*. http://blogs.nature.com/news/2012/11/leaky-pipelines-for-canadian-women-in-research.html. Accessed 25 November 2019

Ozel, B., Kretschmer, H., & Kretschmer, T. (2014). Co-authorship pair distribution patterns by gender. *Scientometrics*, *98*(1), 703–723. https://doi.org/10.1007/s11192-013-1145-y

Paul-Hus, A., Desrochers, N., Rijcke, S. de, & Rushforth, A. D. (2017). The reward system of science. *Aslib Journal of Information Management*. https://doi.org/10.1108/AJIM-07-2017-0168

Porter, A. L., & Youtie, J. (2009). Where does nanotechnology belong in the map of science? *Nature Nanotechnology*, *4*(9), 534–536.

Rifà-Valls, M., Ponferrada, M., & Duarte, L. (2013). *Effective gender equality in research and the academia* (No. Project n°612413). EGERA. http://www.egera.eu/fileadmin/user_upload/Deliverables/Report_on_Mapping___Critical_assessment_of_existing_tools_for_including_gender_in_research_8302.pdf

Roco, M. C. (2011). The long view of nanotechnology development: the National Nanotechnology Initiative at 10 years. *Journal of Nanoparticle Research*, *13*(2), 427–445.

Roco, M. C. (2017). Overview: Affirmation of Nanotechnology between 2000 and 2030. In T. O. Mensah, B. Wang, G. Bothun, J. Winter, & V. Davis (Eds.), *Nanotechnology Commercialization: Manufacturing Processes and Products* (pp. 1–23). John Wiley & Sons, Inc. https://doi.org/10.1002/9781119371762.ch1

Rosenbaum, K. (2017). Different from Discipline to Discipline: Diversity in the Scholarly Publication System. Zenodo. https://doi.org/10.5281/zenodo.1003219

Rossiter, M. W. (1993). The Matthew Matilda effect in science. *Social studies of science*, *23*(2), 325–341.

Sarsons, H. (2017). Recognition for Group Work: Gender Differences in Academia. *American Economic Review*, *107*(5), 141–145. https://doi.org/10.1257/aer.p20171126

Schiebinger, L. (Ed.). (2008). *Gendered innovations in science and engineering*. Stanford, Calif: Stanford University Press.

Schiebinger, L. (2017). *Gender-Responsible Research and Innovation for Small and Medium-Sized Enterprises: Nanotechnology, ICT, and Healthcare*. Responsible Innovation Compass. https://innovation-compass.eu/wp-content/uploads/2017/09/Londa-

Schiebinger_Gender-Responsible-Research-and-Innovation.pdf. Accessed 28 November 2019

Schiebinger, L., & Klinge, I. (2013). Gendered innovations: how gender analysis contributes to research. *European Commission*, *6*, 14.

Schroeder, D., Dalton-Brown, S., Schrempf, B., & Kaplan, D. (2016). Responsible, inclusive innovation and the nano-divide. *NanoEthics*, *10*(2), 177–188.

Schulenburg, M. (2004). *Nanotechnology: Innovation for Tomorrow's World*. European Commission, Research DG. http://www.nanowerk.com/nanotechnology/reports/reportpdf/report1.pdf. Accessed 17 August 2017

Smith-Doerr, L. (2011). Contexts of Equity: Thinking About Organizational and Technoscience Contexts for Gender Equity in Biotechnology and Nanotechnology. In *Nanotechnology and the Challenges of Equity, Equality and Development* (pp. 3–22). Springer. http://link.springer.com/chapter/10.1007/978-90-481-9615-9_1. Accessed 6 January 2014

Sparrow, R. (2007). Negotiating the nanodivides. *New global frontiers in regulation: The age of nanotechnology*, 97–109.

Stix, G. (2001). Little big science. *Scientific American*, *285*(3), 26–31.

Sugimoto, C. R., Ahn, Y. Y., Smith, E., Macaluso, B., & Lariviére, V. (2019, February 9). Factors affecting sex-related reporting: a cross-disciplinary bibliometric analysis of medical research. *The Lancet*. https://iu.tind.io/record/1919. Accessed 3 September 2020

Tahmooresnejad, L., & Beaudry, C. (2015). Does Government Funding Have The Same Impact On Academic Publications And Patents? The Case Of Nanotechnology In Canada. *International Journal of Innovation Management*, *19*(03), 1540001.

Tahmooresnejad, L., Beaudry, C., & Schiffauerova, A. (2015). The role of public funding in nanotechnology scientific production: Where Canada stands in comparison to the United States. *Scientometrics*, *102*(1), 753–787.

The Royal Society. (2004). *Nanoscience and nanotechnologies: opportunities and uncertainties*. Royal Society and Royal Academy of Engineering London. http://www.nanotec.org.uk/report/Nano%20report%202004%20fin.pdf

Thiriet, P. D., Franco, A. D., Cheminée, A., Guidetti, P., Bianchimani, O., Basthard-Bogain, S., et al. (2016). Abundance and Diversity of Crypto- and Necto-Benthic Coastal Fish Are Higher in Marine Forests than in Structurally Less Complex Macroalgal Assemblages. *PLOS ONE*, *11*(10), e0164121. https://doi.org/10.1371/journal.pone.0164121

Toren, N. (1988). Women at the top: Female full professors in higher education in Israel. *Higher education*, *17*(5), 525–544.

Toutkoushian, R. K. (1994). Using Citations to Measure Sex Discrimination in Faculty Salaries. *The Review of Higher Education*, *18*(1), 61–82.

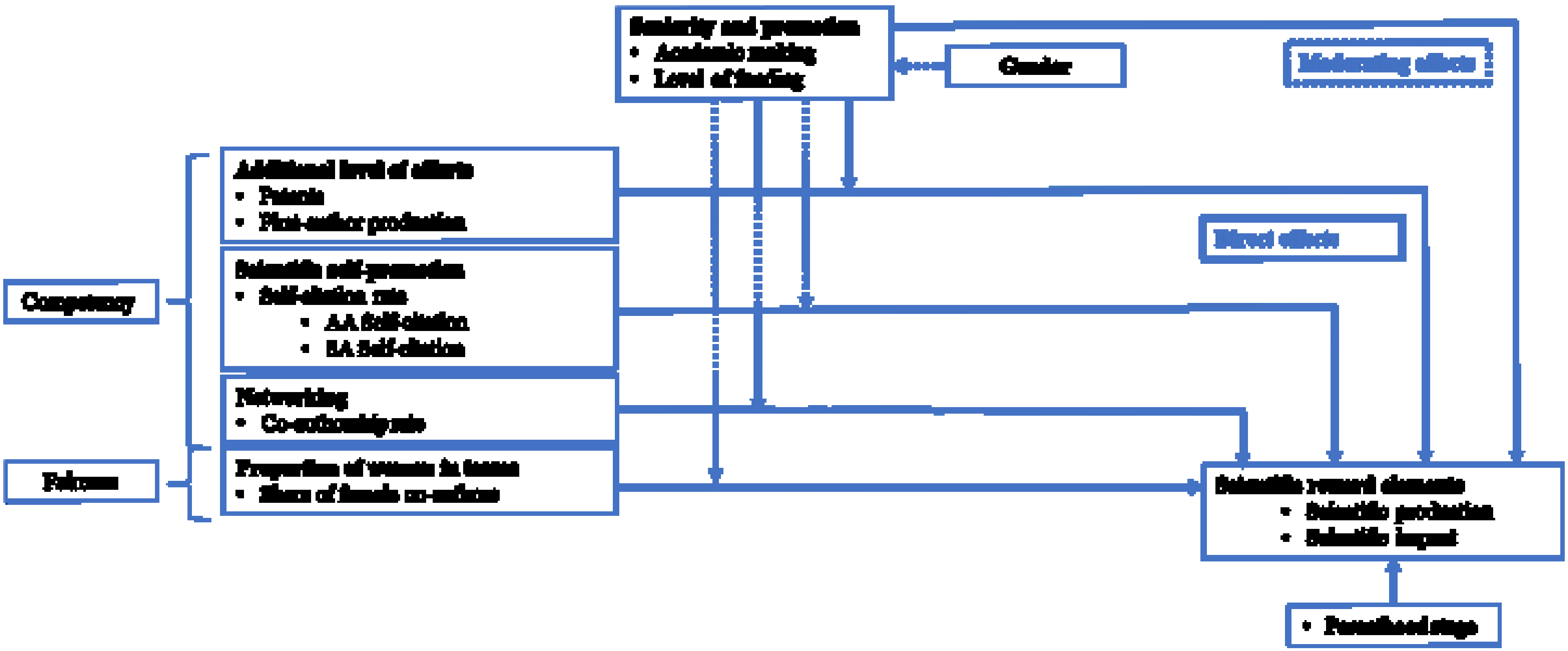
Tscharntke, T., Hochberg, M. E., Rand, T. A., Resh, V. H., & Krauss, J. (2007). Author Sequence and Credit for Contributions in Multiauthored Publications. *PLOS Biol*, *5*(1), e18. https://doi.org/10.1371/journal.pbio.0050018

Uddin, S., Hossain, L., & Rasmussen, K. (2013). Network Effects on Scientific Collaborations. *PLOS ONE*, *8*(2), e57546. https://doi.org/10.1371/journal.pone.0057546

UNESCO. (2007). *Science, technology and gender: an international report*. Paris: UNESCO Publishing. http://unesdoc.unesco.org/images/0015/001540/154045e.pdf. Accessed 2 October 2017

UNESCO. (2014). *Report of the international bioethics committee on the principle of non-discrimination and non-stigmatization* (pp. 23–27). http://unesdoc.unesco.org/images/0022/002211/221196E.pdf. Accessed 13 June 2016

Zamzami, N., & Schiffauerova, A. (2017). The impact of individual collaborative activities on knowledge creation and transmission. *Scientometrics*, *111*(3), 1385–1413.


Seniority and promotion
• Academic ranking
• Level of funding
Gender
Moderating effects
Additional level of efforts
• Patents
• First-author production
Scientific self-promotion
• Self-citation rate
• AA Self-citation
• SA Self-citation
Networking
• Co-authorship rate
Proportion of women in teams
• Share of female co-authors
Competency
Fairness
Direct effects
Scientific reward elements
• Scientific production
• Scientific impact
• Parenthood stage

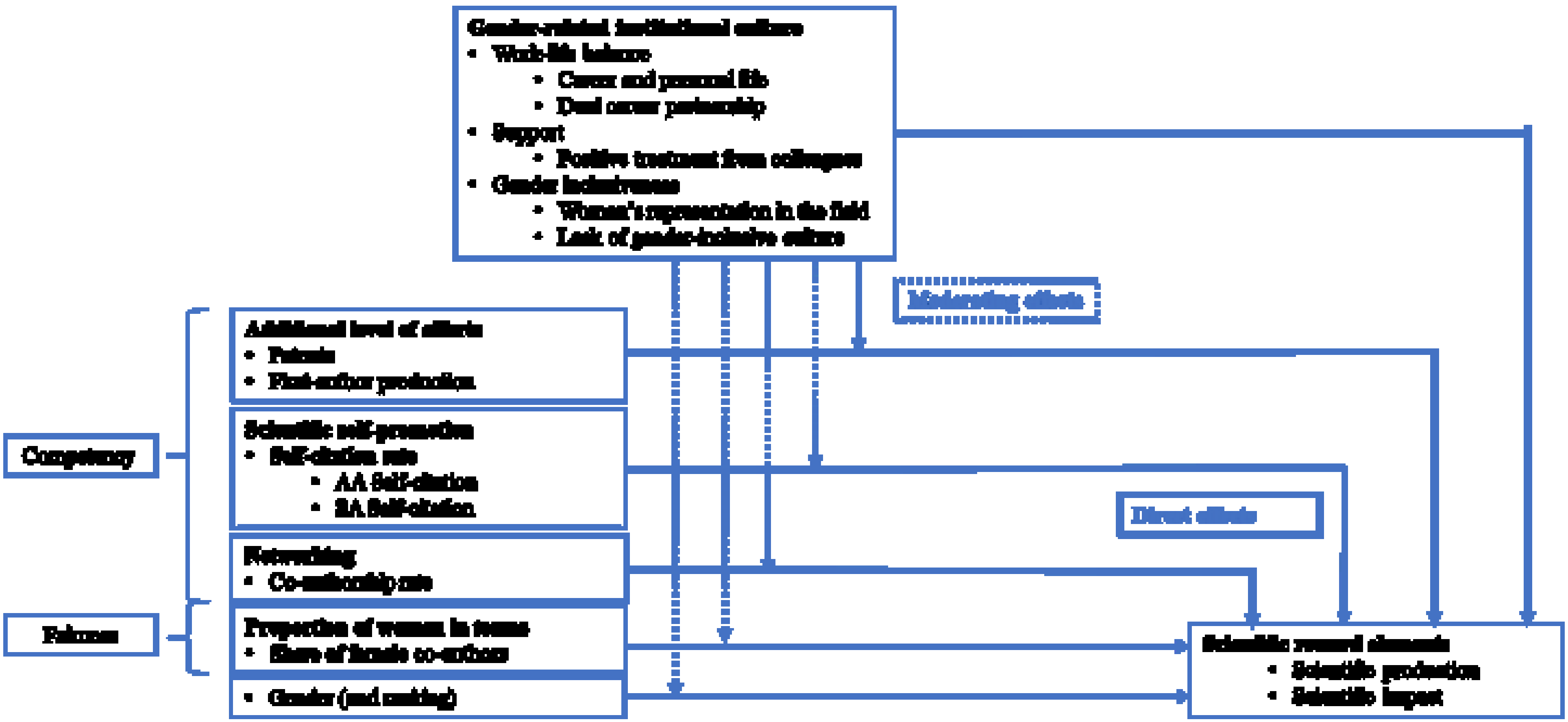

Gender-related institutional culture
Work-life balance
Career and personal life
Dual career partnership
Support
Positive treatment from colleagues
Gender inclusiveness
Women's representation in the field
Lack of gender-inclusive culture
Moderating effects
Additional level of efforts
Patents
First-author production
Scientific self-promotion
Self-citation rate
AA Self-citation
SA Self-citation
Networking
Co-authorship rate
Proportion of women in teams
Share of female co-authors
Gender (and ranking)
Competency
Fairness
Direct effects
Scientific reward elements
Scientific production
Scientific impact

Fig3

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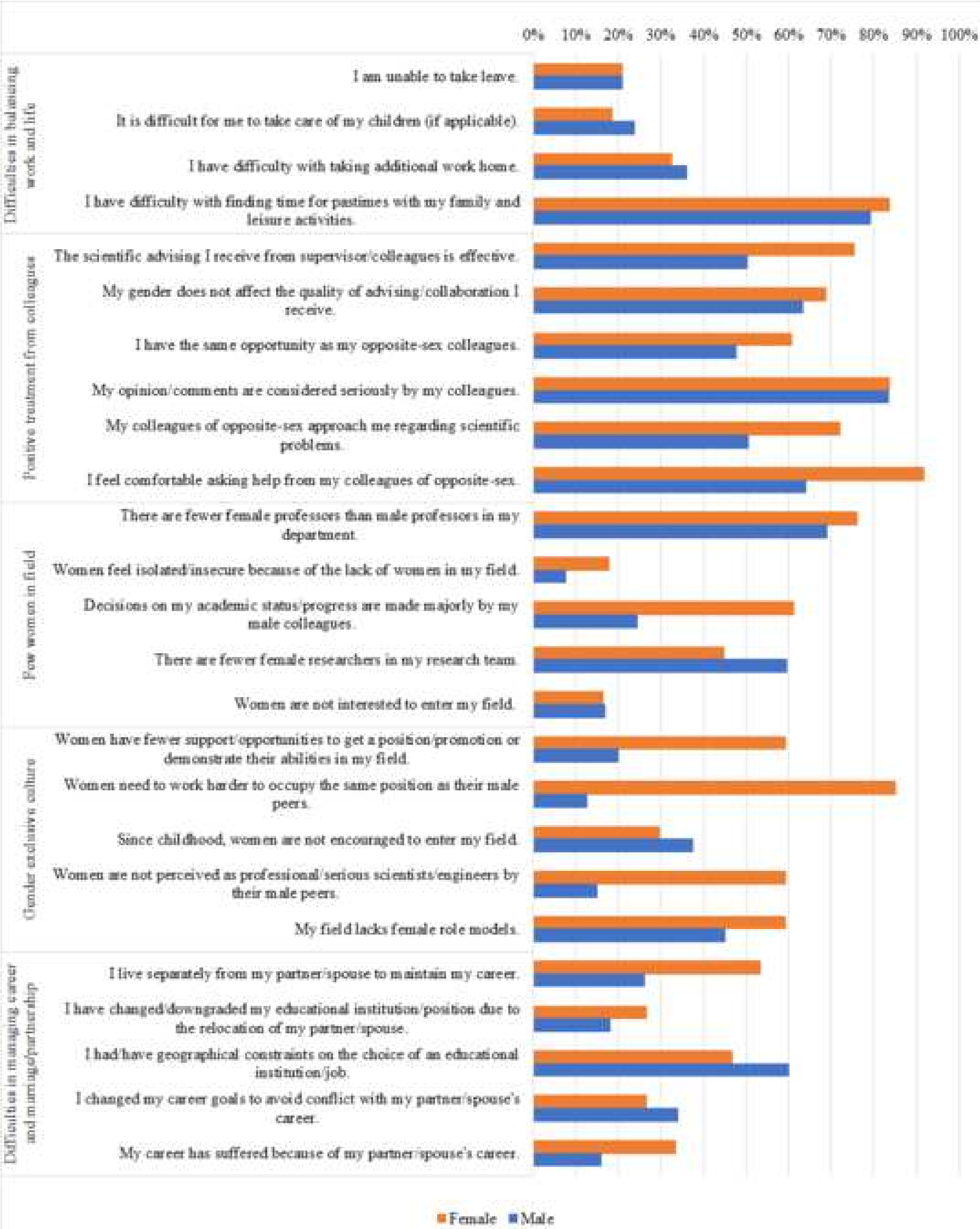

Fig4

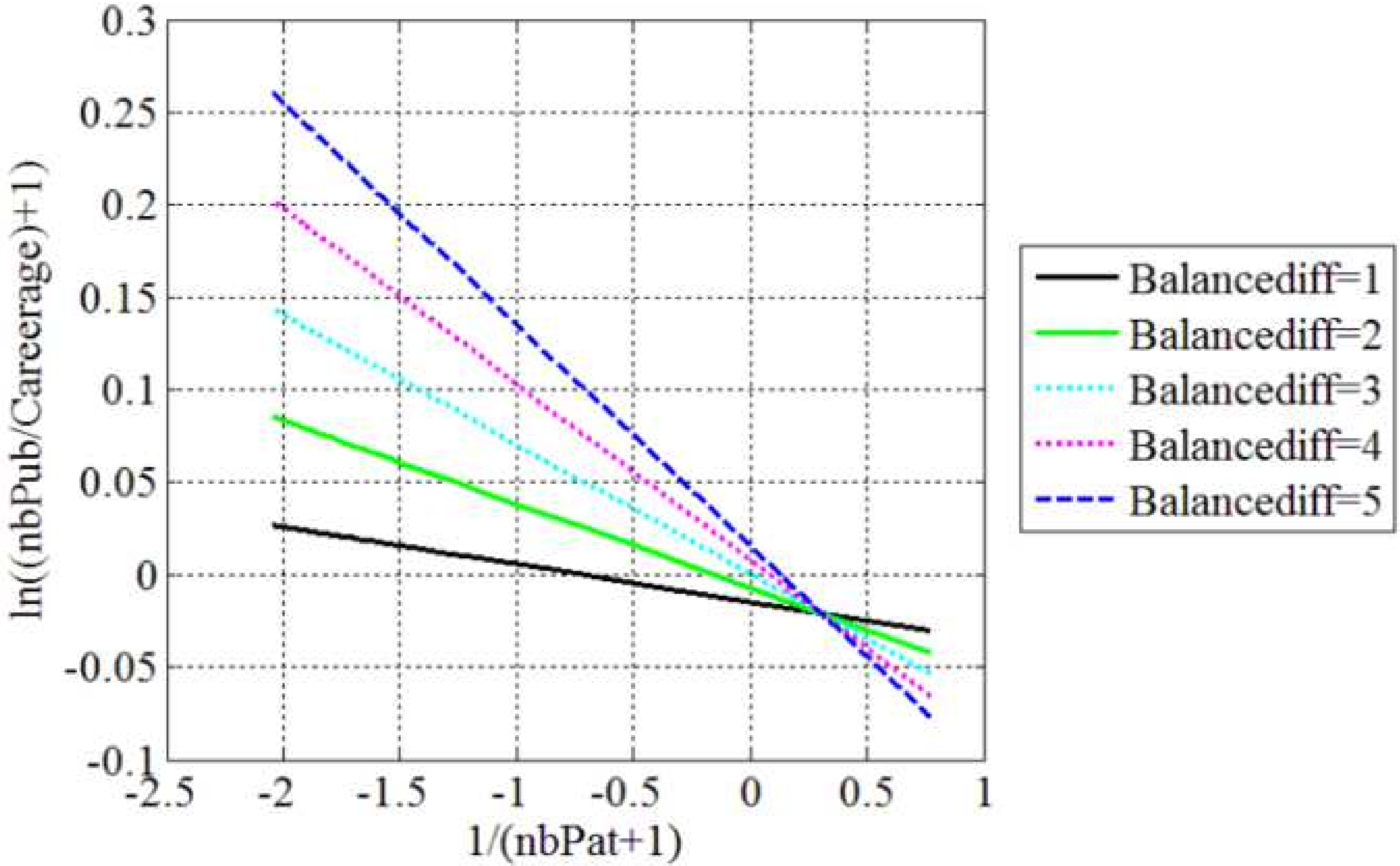

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Fig5

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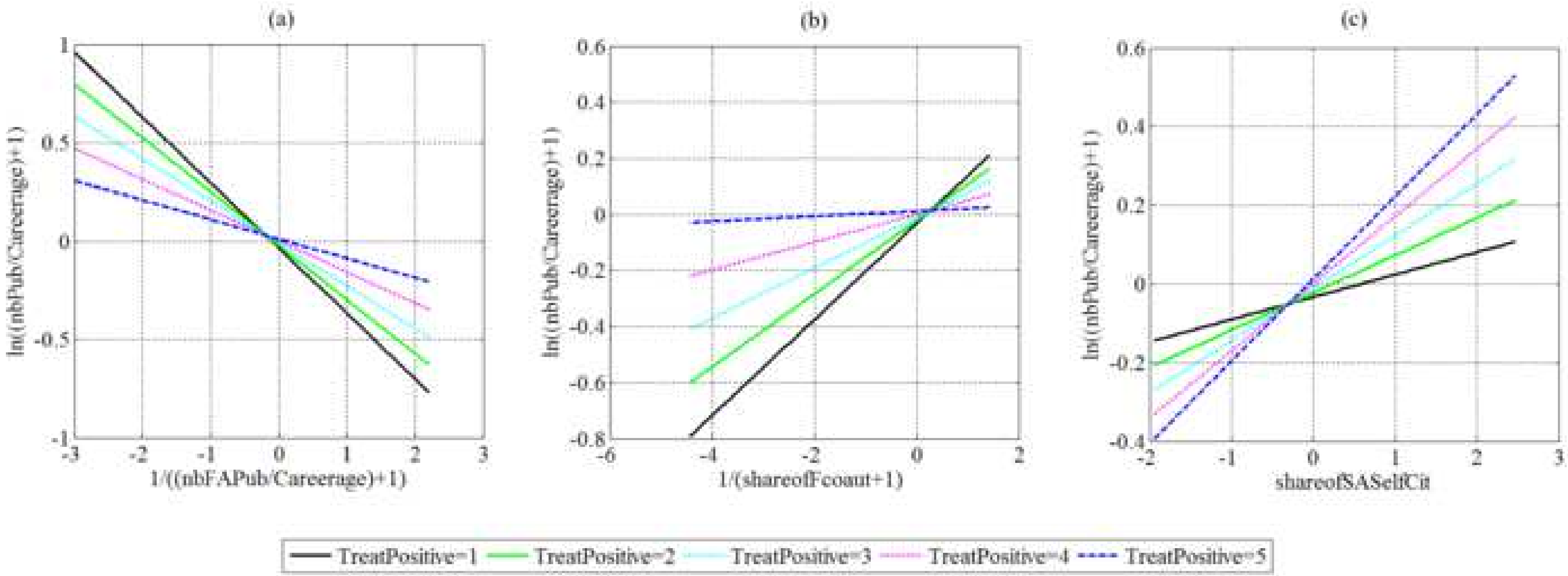

Fig6

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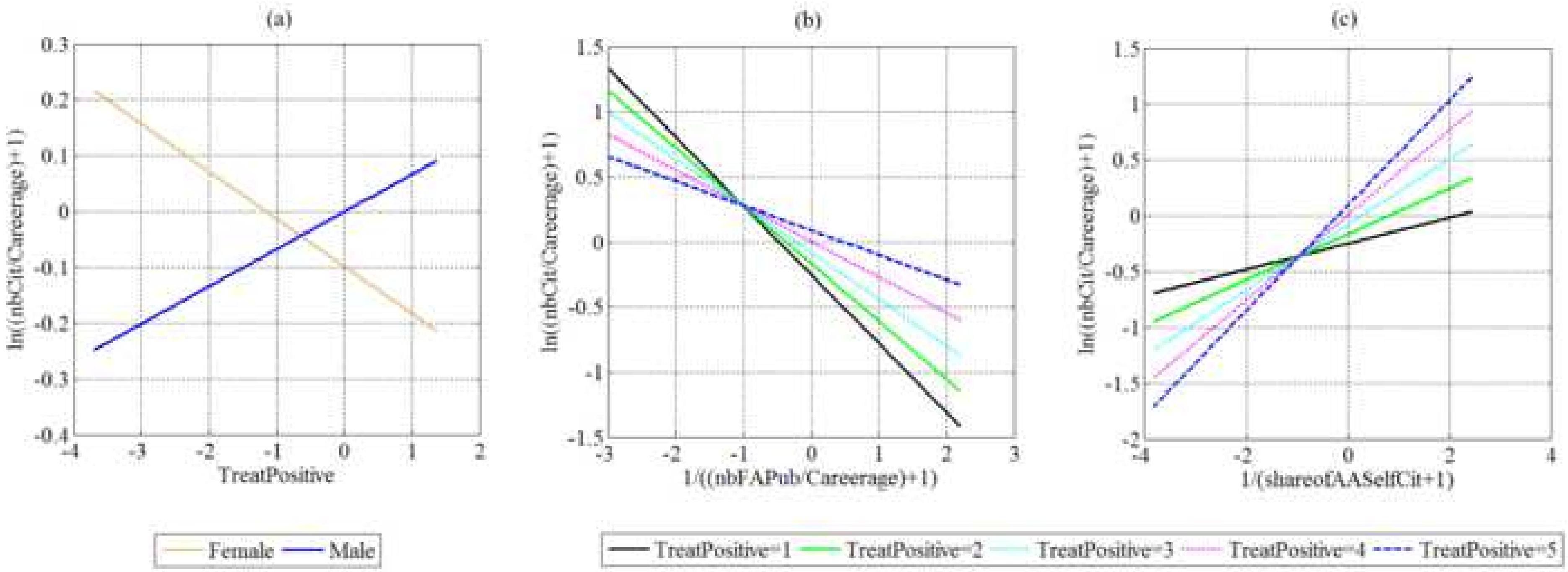

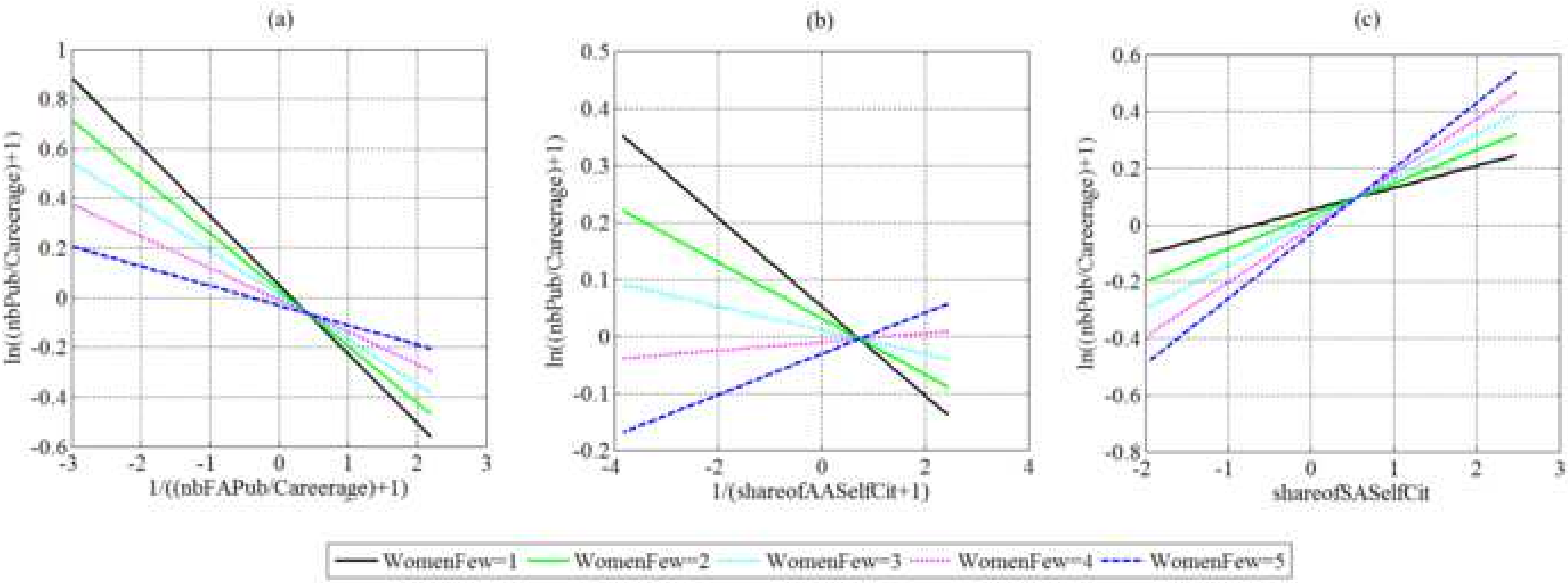
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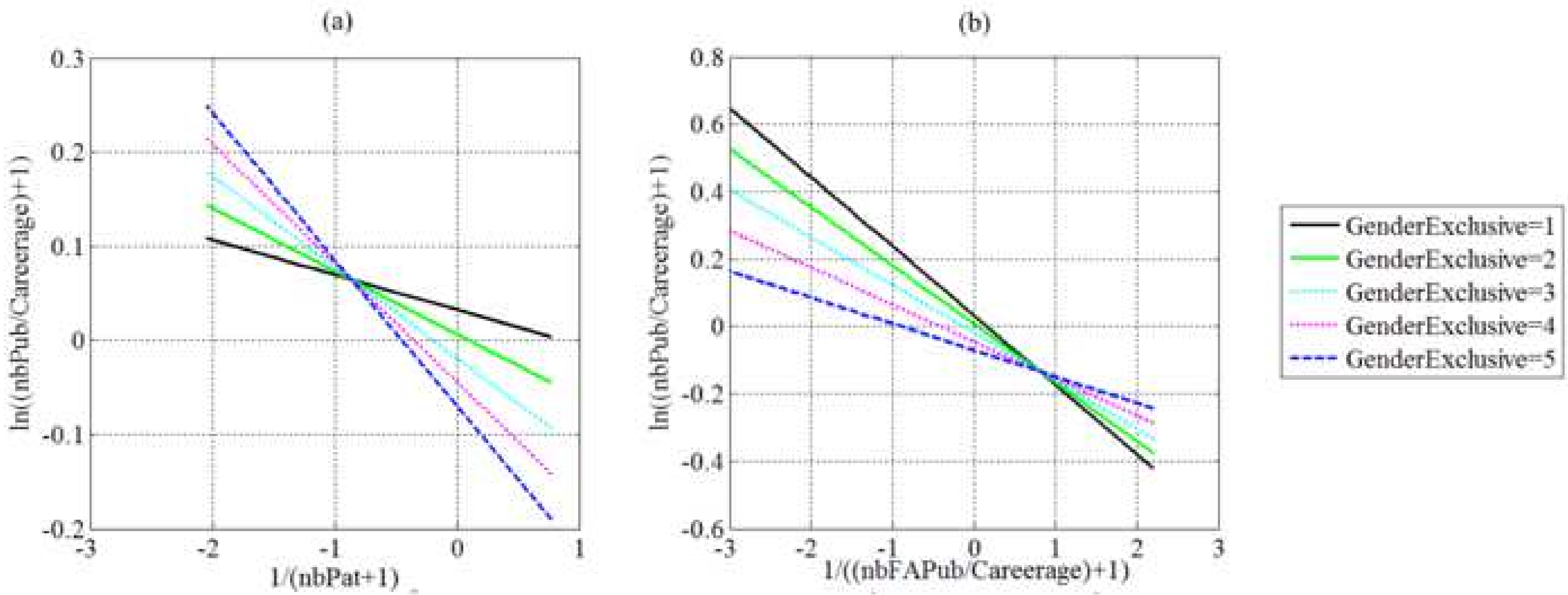
Fig8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GenderExclusive=3
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GenderExclusive=5

Fig9

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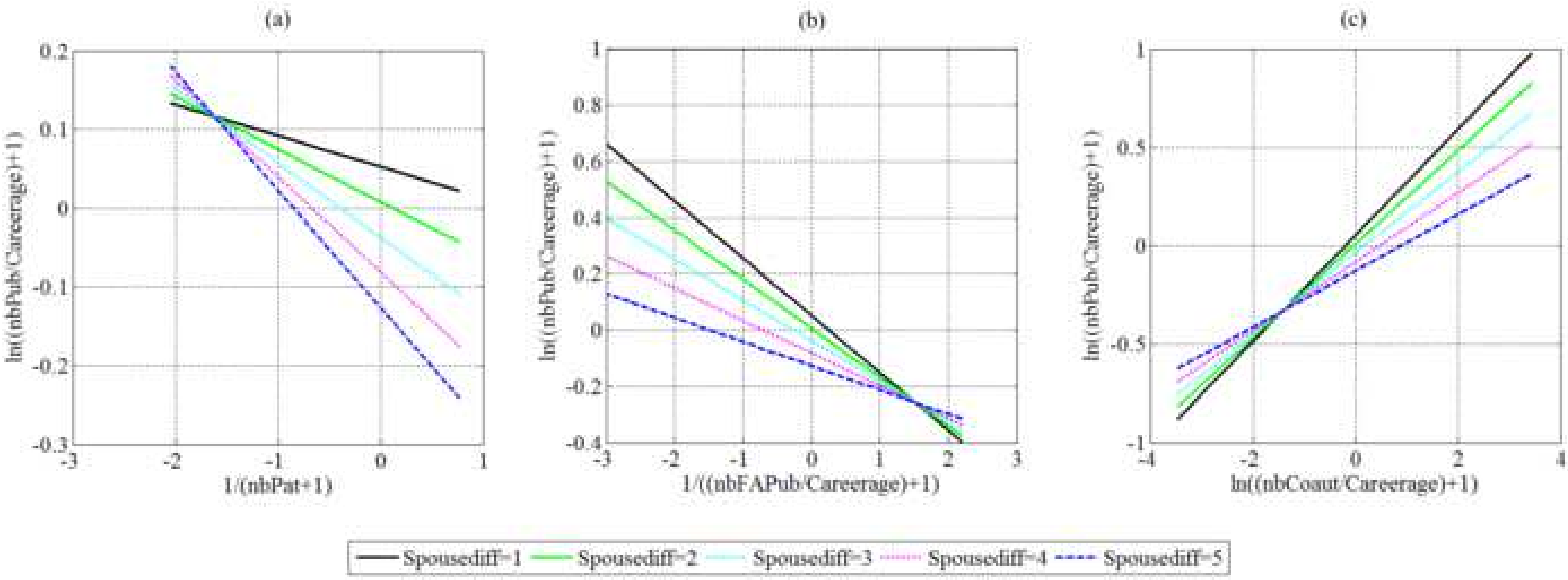

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